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THE DIGESTIBILITY OF CANADIAN FEEDING STUFFS.

IV. RAW POTATOES, DRIED POTATOES AND SOAKED DRIED POTATOES

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The experiments reported in this paper were undertaken to determine the comparative digestibility of the nutrients of raw potatoes and of a dried potato product; also to determine the effect on the digestibility, if any, of soaking the dried potatoes before feeding.

The raw potatoes were graded, edible potatoes grown on the Central Experimental Farm, Ottawa. The dried potatoes were obtained from a fruit dehydrating plant by the Kentville Experimental Station, Nova Scotia. The potatoes had been pulped and placed on trays in a steam dehydrator. The inlet temperature of the dehydrator was 180° F. and the outlet temperature was 165° F. They were ground to pass a one-fifth inch mesh sieve with 24% passing a one-sixtieth inch mesh. The soaked dried potatoes were the above product soaked for 12 hours before feeding at a ratio of 2 parts by weight of water to 1 part of dried potatoes.

LITERATURE

The potato has been grown primarily for human consumption. Livestock feeders, however, have utilized surplus production and cull potatoes for all classes of livestock. They have been fed raw, cooked, dehydrated, and pressed and dehydrated. Both the potatoes and the stalks and leaves have been made into ensilage. By-products of starch manufacture have been marketed as a stock feed and also a by-product resulting from the extraction of certain nitrogenous substances from the potato. A German product known as "Kartoffelschlempe" is made from potatoes, malt and yeast.

A number of investigators have determined the digestibility of potatoes and of various potato products. Their data have been compiled in Table 1. These data indicate that swine, sheep, cattle and horses all digest the carbohydrates of the potato very efficiently. Swine gave higher coefficients of digestibility for nitrogen-free extract than did other classes of livestock.

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TABLE 1.—COEFFICIENTS OF DIGESTIBILITY OF POTATOES AND POTATO PRODUCTS
(Coefficients in per cent)

Type of potato product	Authority	Dry matter	Organic matter	Nitrogen	Crude fibre	N-free extract
		Determinations with Swine				
Raw	Snyder (8)	97.0	—‡	84.5	—	—
Cooked	Snyder (8)	95.0	—	82.0	—	—
Flakes*	Fingerling (2)	—	95.1	70.5	84.9	98.3
Cuttings†	Fingerling (2)	—	92.8	29.2	70.3	96.7
Dried	Kellner, Just, Eisenkolbe and Poppe (4)	—	91.3	58.8	73.2	94.5
Pressed dried	Kellner and Neumann (5)	—	94.5	26.7	85.3	97.9
Pressed dried	Kellner and Neumann (5)	—	90.4	—	72.7	96.9
Mean values		96.0	92.8	58.6	77.3	96.9
		Determinations with Sheep				
Raw	Woods (15)	76.0	77.0	44.6	—	90.3
Raw	Völtz and Dietrich (10)	—	84.0	44.0	—	95.0
Cooked	Woods (15)	80.0	81.0	43.4	—	92.1
Cooked	Völtz and Dietrich (10)	—	80.0	59.0	13.0	96.0
Cooked	Watson and Horton (12)	—	88.1	67.8	—	94.2
Dried	Kellner, Volhard and Honcamp (6)	80.1	81.5	19.5	—	92.0
Dried	Kellner, Just, Eisenkolbe and Poppe (4)	—	86.5	31.9	—	94.4
Mean values		78.7	82.6	44.3	—	93.4
		Determinations with Beef Cattle				
Flakes	Fingerling (2)	79.7	81.4	—	—	92.0
Cuttings	Fingerling (2)	84.0	85.3	30.9	—	95.1
Mean values		81.9	83.4	—	—	93.6
		Determination with Horses				
Steamed	Engler (1)	71.9	73.0	72.1	39.2	90.7
		Determination with Poultry				
Raw	Völtz and Yakuwa (11)	—	78.3	46.9	—	84.5

* Cut, pressed and dehydrated potatoes.
† Cut and dehydrated potatoes.
‡ Coefficients either not given or else not within the range of 0 to 100.

EXPERIMENTAL

Experiments were conducted in 1935, 1936 and 1937. In 1935, the coefficients of digestibility of ground, dried potatoes were determined with four grade Shorthorn steers numbered, in this experiment, 5, 6, 7 and 8.

Their average live weights were 537, 585, 600 and 601 kilogrammes, respectively. The basal ration was composed of a mixed legume and grass hay and soybean oil meal, the digestibility of which ration had been determined in a previous experiment (13). The total daily ration per animal was five kilogrammes of hay, one kilogramme of soybean oil meal and three kilogrammes of dried potatoes.

In 1936 the coefficients of digestibility of pulped raw potatoes were determined with two steers, numbered B and D, from the group described by Watson *et al.* in a previous paper (14). The potatoes were washed, drained over night and pulped previous to feeding. A mixed legume and grass hay of known digestibility (14) was used as the basal ration. Five kilogrammes of hay and fourteen kilogrammes of raw potatoes were fed per animal per day.

In the 1937 experiment the coefficients of digestibility of raw potatoes, dried potatoes and soaked dried potatoes were determined with four grade Shorthorn steers, numbered H, E, F and G in this report. They were $2\frac{1}{2}$ years old and averaged 564, 533, 450 and 449 kilogrammes, respectively, in live weight. The comparisons were made by a 4×4 randomized latin square. The basal ration was a mixed legume and grass hay. The hay alone was fed at a level of 7.0 kilogrammes per animal per day. In the mixed rations the hay was fed at a level of 5.0 kilogrammes, the raw potatoes at 12.0 kilogrammes and the dried potatoes at 3.2 kilogrammes per day. The schedule of the experiment is given in Table 2.

TABLE 2.—SCHEDULE OF THE 1937 EXPERIMENT
COMPOSITION OF RATION

—	Animal H	Animal E	Animal F	Animal G
Period 1	Hay and raw potatoes	Hay and soaked dried potatoes	Hay and dried potatoes	Hay
Period 2	Hay and dried potatoes	Hay and raw potatoes	Hay	Hay and soaked dried potatoes
Period 3	Hay and soaked dried potatoes	Hay	Hay and raw potatoes	Hay and dried potatoes
Period 4	Hay	Hay and dried potatoes	Hay and soaked dried potatoes	Hay and raw potatoes

RESULTS

In all experiments a preliminary period of 12 to 14 days was followed by a collection period of 12 days.

The experimental data are presented in Tables 9 to 14 in the appendix.

Table 3 gives the average composition in percentage of dry matter for raw and dried potatoes fed in 1935, 1936 and 1937.

TABLE 3.—AVERAGE CHEMICAL COMPOSITION OF DRIED POTATOES AND RAW POTATOES
(Mean of five values of dried potatoes and six of raw potatoes)

	Original moisture, %	Percentage of dry matter*				
		Protein (N × 6.25)	Ether extract	Crude fibre	N-free extract	Ash
Dried Potatoes						
Mean	11.24	10.88	0.36	2.41	80.97	5.38
Coeff. of var.†	8.24	9.46	10.47	5.69	1.31	6.57
Standard error	±0.41	±0.46	±0.02	±0.06	±0.47	±0.16
Raw Potatoes						
Mean	78.34	12.65	0.25	2.20	79.90	5.01
Coeff. of var.	1.41	2.80	38.78	4.87	0.64	5.39
Standard error	±0.45	±0.14	±0.04	±0.04	±0.21	±0.11

* Analyses of raw potatoes made on aliquots dried at 70° C. to air-dry weight.
† Fisher's methods (3) have been used in the statistical treatment of the data.

A summary of the coefficients of digestibility for the 1935 and 1936 expe,iments is given in Table 4.

TABLE 4.—COEFFICIENTS OF DIGESTIBILITY OF DRIED POTATOES AND OF RAW POTATOES
(Coefficients in per cent)

	Dry matter	Organic matter	Nitrogen	N-free extract
Dried Potatoes—1935				
Animal No. 5	85.0	85.9	35.0	92.9
Animal No. 6	83.4	84.3	32.1	92.5
Animal No. 7	83.9	84.5	28.8	93.6
Animal No. 8	82.6	83.2	41.9	91.7
Mean	83.7	84.5	34.5	92.7
Coeff. of variation	1.20	1.31	16.16	0.86
Standard error	±0.50	±0.55	±2.79	±0.40
*Raw Potatoes—1936**				
Animal No. B	88.7	89.4	71.1	95.6
Animal No. D	86.9	87.9	68.8	95.6
Mean	87.8	88.7	70.0	95.6

* Nitrogen coefficients calculated on the basis of original nitrogen. (See Table 10 in the appendix.)

In Table 5 the coefficients of digestibility of hay and of the potatoes, calculated from the mixed ration, for the 1937 experiment have been arranged by periods and by animals. In Table 6 the average coefficients of digestibility for the various rations have been presented, while in Table 7 the analysis of variance with the significant differences between two means has been summarized.

TABLE 5.—COEFFICIENTS OF DIGESTIBILITY OF HAY, RAW POTATOES, DRIED POTATOES AND SOAKED DRIED POTATOES ARRANGED BY PERIODS AND BY ANIMALS
(Coefficients in per cent. Treatments shown by Roman Numerals*)

—	Animal	Period 1		Period 2		Period 3		Period 4		Mean
Dry matter	H	(IV)	90.6	(II)	82.3	(III)	85.3	(I)	56.8	78.8
	E	(III)	85.3	(IV)	85.7	(I)	57.2	(II)	87.5	78.9
	F	(II)	83.9	(I)	55.3	(IV)	86.3	(III)	85.0	77.6
	G	(I)	54.5	(III)	85.2	(II)	89.1	(IV)	86.8	78.9
	Means		78.6		77.1		79.3		79.0	78.55
Organic matter	H	(IV)	92.2	(II)	83.2	(III)	86.7	(I)	58.1	80.1
	E	(III)	86.8	(IV)	86.1	(I)	58.2	(II)	89.1	80.1
	F	(II)	85.8	(I)	56.4	(IV)	87.7	(III)	87.0	79.2
	G	(I)	56.0	(III)	86.8	(II)	91.1	(IV)	88.9	80.7
	Means		80.2		78.1		80.9		80.8	80.01
Nitrogen	H	(IV)	69.1	(II)	54.9	(III)	52.7	(I)	61.6	59.6
	E	(III)	51.7	(IV)	66.2	(I)	60.6	(II)	61.1	59.9
	F	(II)	51.1	(I)	54.3	(IV)	47.6	(III)	44.7	49.4
	G	(I)	56.8	(III)	53.3	(II)	54.5	(IV)	64.5	57.3
	Means		57.2		57.2		53.9		58.0	56.54
N-free extract	H	(IV)	95.3	(II)	90.3	(III)	93.1	(I)	69.8	87.1
	E	(III)	94.3	(IV)	93.7	(I)	69.1	(II)	95.6	88.2
	F	(II)	94.0	(I)	67.9	(IV)	93.1	(III)	95.5	87.6
	G	(I)	68.0	(III)	93.0	(II)	96.2	(IV)	97.4	88.7
	Means		87.9		86.2		87.9		89.6	87.89

* I—Hay alone; II—Dried potatoes; III—Soaked dried potatoes; IV—Raw potatoes.

TABLE 6.—AVERAGE COEFFICIENTS OF DIGESTIBILITY* FOR EACH RATION IN PERIODS 1, 2, 3, AND 4

Ration	Dry matter	Organic matter	Nitrogen	N-free extract
Hay	56.0	57.2	58.3	68.7
Dried Potatoes	85.7	87.3	55.4	94.0
Soaked dried potatoes	85.2	86.8	50.6	94.0
Raw potatoes	87.4	88.7	61.9	94.9

(* Coefficients in per cent.)

TABLE 7.—STATISTICAL ANALYSIS OF DATA IN TABLES 5 AND 6

—	Variance due to	Degrees of freedom	Sums of squares of deviations	Variance	Significant difference between two means*
Dry matter	Ration	3	2728.68	909.56	4.29
	Period	3	12.84	4.28	
	Animal	3	4.84	1.61	
	Error	6	36.98	6.16	
	Total	15	2783 34		

TABLE 7.—STATISTICAL ANALYSIS OF DATA IN TABLES 5 AND 6—*Concluded*

—	Variance due to	Degrees of freedom	Sums of squares of deviations	Variance	Significant difference between two means*
Organic matter	Ration	3	2780.24	926.75	4.11
	Period	3	20.40	6.80	
	Animal	3	4.59	1.53	
	Error	6	33.80	5.63	
	Total	15	2839.03		
Nitrogen	Ration	3	273.64	91.21	6.78
	Period	3	39.89	13.30	
	Animal	3	288.84	96.28	
	Error	6	92.03	15.34	
	Total	15	694.40		
N-free extract	Ration	3	1968.24	656.08	3.08
	Period	3	23.12	7.71	
	Animal	3	5.84	1.95	
	Error	6	19.02	3.17	
	Total	15	2016.22		

* Goulden, C. H.—Methods of Statistical Analysis (1936) pp. 97–98.

The effects of animal and of period upon the coefficients of digestibility of dry matter, organic matter and nitrogen-free extract were not significant. The coefficients of digestibility of the nitrogen obtained with animal F were significantly lower than those obtained with animals H, E and G. The average coefficient of digestibility of nitrogen of raw potatoes was significantly higher than that of soaked dried potatoes. The coefficients of digestibility of the dry matter, organic matter and nitrogen-free extract of dried potatoes, soaked dried potatoes and raw potatoes were, in the case of each nutrient, of the same order.

Table 8 is a summary of all the coefficients of digestibility obtained from the three experiments. It includes a second determination of the

TABLE 8.—AVERAGE COEFFICIENTS OF DIGESTIBILITY FOR RAW POTATOES, DRIED POTATOES AND SOAKED DRIED POTATOES IN PER CENT

—	Number of values	Coefficients of digestibility			
		Dry matter	Organic matter	Nitrogen	N-free extract
Raw potatoes—1936–37					
Mean	7	87.7	89.0	65.0	95.1
Coeff. of variation		1.92	2.26	12.22	1.48
Standard error		±0.64	±0.76	±3.00	±0.53
Dried potatoes—1935 and 1937					
Mean	8	84.7	85.9	44.9	93.4
Coeff. of variation		2.84	3.30	26.93	2.09
Standard error		±0.85	±1.00	±4.28	±0.69
Soaked dried potatoes—1937					
Mean	4	85.2	86.8	50.6	94.0
Coeff. of variation		0.17	0.15	7.88	1.25
Standard error		±0.07	±0.07	±1.99	±0.59

coefficients of digestibility of raw potatoes with animal H of the 1937 experiment.[5] The average coefficient of digestibility for the nitrogen of raw potatoes was significantly higher than that for dried potatoes or soaked dried potatoes.

DISCUSSION OF RESULTS

From the data in Table 3 it is concluded that, on the dry matter basis, the dried potatoes were lower in total protein than the raw potatoes but equal to them in regard to the other constituents. The difference in protein may not be entirely due to the process of drying since the dried potatoes and the raw potatoes were not from the same crop.

The data in Table 8 show that the potato is a highly digestible carbohydrate feed. Drying had no deleterious effect upon the digestibility of the carbohydrate of the potato. The coefficients of digestibility for the nitrogen of raw potatoes were significantly higher than those for dried potatoes or soaked dried potatoes. In the 1935 experiment the coefficients of digestibility of the nitrogen of the dried potatoes were lower than those determined in 1937. The basal ration of the 1935 experiment contained soybean oil meal and the digestibility of the nitrogen of this latter feed may have been modified by the starch of the potatoes. This would affect the digestibility of the nitrogen of the dried potatoes as calculated.

The 1937 results show that soaking the dried potatoes did not increase the availability of the potato nutrients. Soaking is a time-consuming process due both to the time involved in soaking and to the necessity of feeding as a separate entity of the ration. The authors, therefore, recommend that dried potatoes be fed dry and mixed with the other ingredients of the grain ration for cattle.

Monetary values have been assigned to raw potatoes using the method of Petersen (7) as applied to Canadian conditions by Stothart (9). In employing this method it was assumed that, in feeding practice, units of protein and non-protein nutrients in potatoes were equivalent to units in barley and linseed oil meal. With barley worth $26.00 and linseed oil meal worth $34.00 per ton of dry matter, potatoes would be worth $25.60 per ton of dry matter. With barley at $35.00 and linseed oil meal at $43.00, potatoes would be worth $34.88 per ton of dry matter. Expressed on the original basis, raw potatoes would be worth 17 cents and 23 cents, respectively per bushel.

SUMMARY

With grade Shorthorn steers as experimental animals, digestibility trials were conducted with raw potatoes, dried potatoes and soaked dried potatoes.

The carbohydrate nutrients of the potato were highly digestible and the coefficients of digestibility obtained in this study were of the same general order as those obtained by other investigators.

It was shown that the drying of potatoes had no practical deleterious effects upon the availability of the nutrients of the potato.

Soaking the dried potatoes did not increase their value as a feed for beef cattle.

[5] Table 14 in the Appendix.

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APPENDIX

TABLE 9.—CHEMICAL COMPOSITION OF FEEDING STUFFS

Year	Period	Original moisture %	Percentage of dry matter				
			Protein (N×6.25)	Ether extract	Crude fibre	N-free extract	Ash
Hay							
1935		7.27	12.22	2.56	30.31	46.93	7.98
1936		11.06	12.67	1.80	35.92	41.50	8.11
1937	1	13.23	12.78	2.47	31.88	45.67	7.20
1937	2	13.40	11.95	2.45	32.62	45.94	7.04
1937	3	13.94	12.84	2.44	33.60	43.75	7.37
1937	4	14.17	14.03	2.43	31.79	44.09	7.66
1937	5	13.46	13.32	2.61	31.65	44.69	7.73
Soybean Oil Meal							
1935		8.01	40.58	6.31	8.52	37.11	7.48
Dried Potatoes							
1935		10.98	9.12	0.36	2.58	82.84	5.10
1937	1	12.02	11.66	0.34	2.33	80.44	5.23
1937	2	12.37	11.58	0.32	2.24	80.81	5.05
1937	3	10.20	11.04	0.42	2.38	80.38	5.78
1937	4	10.61	11.00	0.37	2.51	80.38	5.74

TABLE 10.—CHEMICAL COMPOSITION OF RAW POTATOES

Year	Period	Analysis of original material		Percentage of dry matter*				
		Moisture, %	Nitrogen† %	Protein (N×6.25)	Ether extract	Crude fibre	N-free extract	Ash
1936		76.24	0.529	12.87	0.43	2.07	79.87	4.76
1937	1	78.18	0.443	12.36	0.25	2.21	79.71	5.47
1937	2	78.79	0.458	12.81	0.16	2.28	80.01	4.74
1937	3	79.43	0.398	11.66	0.17	2.33	80.75	5.09
1937	4	78.69	0.452	12.89	0.24	2.07	79.88	4.92
1937	5	78.73	0.464	13.29	0.25	2.21	79.17	5.07

* Analyses on aliquot samples dried at 70° C. to air-dry weight.
† All nitrogen coefficients of digestibility calculated from these original nitrogens.

TABLE 11.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY OF DRIED POTATOES, 1935
(Collection period of 12 days; weights in kilogrammes; coefficients in per cent.)

——	Original weight	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract
In feeds							
Hay	60.000	55.638	51.198	1.088	1.422	16.866	26.112
Soybean oil meal	12.000	11.039	10.213	0.717	0.696	0.941	4.483
Dried potatoes	36.000	32.047	30.413	0.468	0.115	0.828	26.546
Total	108.000	98.724	91.824	2.273	2.233	18.635	57.141
In feces							
Animal No. 5	194.038	27.980	24.654	0.843	0.689	10.403	8.919
Animal No. 6	204.202	28.485	25.142	0.857	0.674	10.608	9.046
Animal No. 7	205.590	28.340	25.065	0.872	0.629	10.823	8.752
Animal No. 8	205.173	28.739	25.461	0.811	0.687	10.997	9.258
*Coefficients of digestibility of,**							
Hay		61.4	62.7	58.8	57.8	42.4	76.0
Soybean oil meal		84.6	87.6	87.3	87.8	106.0	80.9
Digested from							
Hay		34.162	32.101	0.640	0.822	7.151	19.845
Soybean oil meal		9.339	8.947	0.626	0.611	0.995	3.703
Total		43.501	41.048	1.266	1.433	8.146	23.548
Digested from dried Potatoes							
Animal 5		27.243	26.122	0.164	0.111	0.086	24.674
Animal 6		26.738	25.634	0.150	0.126	–	24.547
Animal 7		26.883	25.711	0.135	0.171	–	24.841
Animal 8		26.484	25.315	0.196	0.113	–	24.335
Coefficients of digestibility of dried potatoes							
Animal 5		85.0	85.9	35.0	96.5	10.4	92.9
Animal 6		83.4	84.3	32.1	109.6	–	92.5
Animal 7		83.9	84.5	28.8	148.7	–	93.6
Animal 8		82.6	83.2	41.9	98.3	–	91.7

* Sci. Agr. 17, 1, (1936).—1934 results.

TABLE 12.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY OF RAW POTATOES, 1936
(Collection period of 12 days; weights in kilogrammes; coeficients in per cent.)

—	Original weight	Dry matter	Organic matter	Nitro-gen	Ether extract	Crude fibre	N-free extract
In feeds							
Hay	60.000	53.364	49.036	1.081	0.961	19.168	22.146
Raw potatoes	168.000	39.917	38.017	0.889	0.172	0.826	31.882
Total	228.000	93.281	87.053	1.970	1.133	19.994	54.028
In feces							
Animal B	178.289	30.194	27.223	0.714	0.616	12.688	9.973
Animal D	222.331	30.915	27.799	0.734	0.652	12.935	9.973
Coefficient of digestibility of Hay*		51.9	52.7	57.7	36.8	41.7	61.3
Digested from Hay		27.696	25.842	0.624	0.354	7.993	13.575
Digested from raw potatoes							
Animal B		35.391	33.988	0.632	0.163	–	30.480
Animal D		34.670	33.412	0.612	0.127	–	30.480
Coefficient of digestibility of raw potatoes							
Animal B		88.7	89.4	71.1	94.8	–	95.6
Animal D		86.9	87.9	68.8	73.8	–	95.6

* From Sci. Agr. 18 : 10; 586. (1935–36 results.)

TABLE 13.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY OF HAY, 1937
(Collection period of 12 days; weights in kilogrammes; coefficients in per cent.)

—	Original weights	Dry matter	Organic matter	Nitro-gen	Ether extract	Crude fibre	N-free extract
In hay							
Period 1	84.000	72.887	67.639	1.490	1.800	23.236	33.287
Period 2	84.000	72.744	67.623	1.391	1.782	23.729	33.419
Period 3	84.000	72.290	66.962	1.485	1.764	24.289	31.627
Period 4	84.000	72.097	66.574	1.619	1.752	22.920	31.788
In feces							
Animal H (4)*	193.952	31.158	27.865	0.622	0.816	13.843	9.587
Animal E (3)	170.974	30.966	27.968	0.585	0.793	14.009	9.779
Animal F (2)	230.830	32.531	29.512	0.636	0.823	14.401	10.735
Animal G (1)	190.549	33.147	29.756	0.644	0.925	14.233	10.644
Coefficient of digestibility							
An mal H		56.8	58.1	61.6	53.4	39.6	69.8
Animal E		57.2	58.2	60.6	55.0	42.3	69.1
Animal F		55.3	56.4	54.3	53.8	39.3	67.9
Animal G		54.5	56.0	56.8	48.6	38.7	68.0
Mean		56.0	57.2	58.3	52.7	40.0	68.7

* Number of period in brackets.

TABLE 14.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY OF RAW POTATOES, DRIED POTATOES AND SOAKED DRIED POTATOES—1937

(Collection period of 12 days; weights in kilogrammes; coefficients in per cent)

——	Original weight	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract
In hay							
Period 1	60.000	52.062	48.314	1.064	1.286	16.597	23.777
Period 2	60.000	51.960	48.302	0.993	1.273	16.949	23.870
Period 3	60.000	51.636	47.830	1.061	1.260	17.350	22.591
Period 4	60.000	51.498	47.553	1.156	1.251	16.371	22.705
Period 5	60.000	51.924	47.910	1.107	1.355	16.434	23.205
In raw potatoes							
Period 1	144.000	31.421	29.702	0.638	0.079	0.694	25.046
Period 2	144.000	30.542	29.094	0.659	0.049	0.696	24.437
Period 3	144.000	29.621	28.113	0.573	0.050	0.690	23.919
Period 4	144.000	30.686	29.176	0.650	0.074	0.635	24.512
Period 5	144.000	30.629	29.076	0.668	0.077	0.677	24.249
In dried and soaked dried potatoes							
Period 1	38.400	33.784	32.017	0.630	0.115	0.787	27.176
Period 2	38.400	33.650	31.951	0.623	0.108	0.754	27.193
Period 3	38.400	34.483	32.490	0.609	0.145	0.821	27.717
Period 4	38.400	34.326	32.356	0.604	0.127	0.862	27.591
Digested from hay							
Period 1		29.155	27.636	0.620	0.678	6.639	16.335
Period 3		29.098	27.629	0.579	0.671	6.780	16.399
Period 3		28.916	27.359	0.619	0.664	6.940	15.520
Period 4		28.839	27.200	0.674	0.759	6.548	15.598
Period 5		29.077	27.405	0.645	0.714	6.574	15.942
In feces of raw potato ration							
Animal H (1)*	168.899	25.849	22.985	0.641	0.734	10.050	8.615
Animal E (2)	180.961	27.236	24.730	0.637	0.616	11.445	9.007
Animal F (3)	232.330	26.787	23.940	0.742	0.664	10.747	8.725
Animal G (4)	206.965	26.712	23.600	0.713	0.673	11.179	7.746
Animal H (5)	199.027	26.283	23.245	0.680	0.712	10.227	8.529
Digested from raw potatoes							
Animal H (1)		28.479	27.395	0.441	–	0.602	23.873
Animal E (2)		26.168	25.037	0.436	0.035	–	22.901
Animal F (3)		25.554	24.644	0.273	–	0.353	22.265
Animal G (4)		26.633	25.929	0.419	–	–	23.873
Animal H (5)		27.193	26.336	0.450	0.006	0.310	22.983
Coefficient of digestibility of raw potatoes							
Animal H (1)		90.6	92.2	69.1	–	86.7	95.3
Animal E (2)		85.7	86.1	66.2	71.4	–	93.7
Animal F (3)		86.3	87.7	47.6	–	51.2	93.1
Animal G (4)		86.8	88.9	64.5	–	–	97.4
Animal H (5)		88.8	90.6	67.4	7.8	45.8	94.8
In feces of dried potato ration							
Animal H (2)	212.102	28.811	26.039	0.695	0.723	11.501	10.116
Animal E (4)	172.634	26.960	23.895	0.717	0.714	10.816	8.309
Animal F (1)	199.828	28.344	25.215	9.752	0 796	11.046	9.084
Animal G (3)	198.241	26.484	23.375	0.719	0.614	10.676	8.112

* Numbers in brackets refer to periods.

TABLE 14.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY OF RAW POTATOES, DRIED POTATOES AND SOAKED DRIED POTATOES—1937—*Concluded*

(Collection period of 12 days; weights in kilogrammes; coefficients in per cent)—*Concluded*

—	Original weight	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract
Digested from dried potatoes							
Animal H (2)		27.701	26.585	0.342	–	–	24.548
Animal E (4)		30.025	28.814	0.369	0.005	–	26.389
Animal F (1)		28.347	27.480	0.322	–	–	25.534
Animal G (3)		30.719	29.586	0.332	0.127	0.555	26.676
Coefficient of digestibility of dried potatoes							
Animal H (2)		82.3	83.2	54.9	–	–	90.3
Animal E (4)		87.5	89.1	61.1	3.9	–	95.6
Animal F (1)		83.9	85.8	51.1	–	–	94.0
Animal G (3)		89.1	91.1	54.5	87.6	67.6	96.2
In feces of soaked dried potato ration							
Animal H (3)	210.117	27.786	24.780	0.730	0.672	10.984	8.980
Animal E (1)	176.410	27.868	24.894	0.748	0.705	10.947	9.004
Animal F (4)	236.887	27.821	24.546	0.816	0.729	11.062	8.335
Animal G (2)	187.829	27.831	24.903	0.705	0.693	10.670	9.365
Digested from soaked dried potatoes							
Animal H (3)		29.417	28.181	0.321	0.069	0.247	25.808
Animal E (1)		28.823	27.801	0.326	0.018	–	25.614
Animal F (4)		29.164	28.163	0.270	–	–	26.363
Animal G (2)		28.681	27.721	0.332	0.017	0.253	25.299
Coefficient of digestibility of soaked dried potatoes							
Animal H (3)		85.3	86.7	52.7	47.6	30.1	93.1
Animal E (1)		85.3	86.8	51.7	15.7	–	94.3
Animal F (4)		85.0	87.0	44.7	–	–	95.5
Animal G (2)		85.2	86.8	53.3	15.7	33.6	93.0

ANALYSIS OF SOIL FOR SEEDS

A METHOD OF CONCENTRATING THE SEEDS FROM SOIL FOR THE PURPOSE OF COUNTING AND NAMING THE SEEDS IN A SOIL SURVEY

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INTRODUCTION

In addition to the seeds in soil, there are pebbles, sand, and fine particles down to colloidal sizes, of inorganic origin derived from rock decay. This material constitutes the largest portion of the soil.

Mixed with this is a further portion of organic origin, consisting of vegetable matter from leaves, roots, and other plant remains more or less decayed, and varying in size of particle from chunks of wood down to humus of microscopic sizes. A small portion may be of animal remains such as snail eggs, casts of wood lice, small shells, etc.

If the soil is from a cultivated piece of ground there may be also particles derived from fertilizers, ash, fragments of brick and pottery, pieces of coke and such material.

The specific gravity of the particles ranges from 2.6 and over, down to about 1.5 for the inorganic matter and to less than 1 for some of the organic matter. Thus the soil consists of particles of a wide range of specific gravity and of size. The seeds are in the lighter portion.

From this mixture it is desired to concentrate the seeds into the smallest possible bulk in order to reduce the labour of sorting to a minimum, and to do this without destroying or so damaging the seeds as to make identification impossible.

METHODS

An outline of a method of concentration that has proved successful follows:—

(1) Dampen the soil if necessary until the earthy parts are soft.

(2) Screen through a 4-mesh screen breaking the lumps if any.

(3) Wash the over-size clean. Only the very largest species of seeds will be retained on the screen and are easily picked out. This operation is to remove the larger pebbles that might damage the seeds in subsequent operations.

(4) Feed the material that passes the 4-mesh screen into a tumbling barrel with a considerable flow of water. The operation of the barrel disintegrates the soil and washes out the lighter portion that contains the seeds. Many of the seeds are heavier than water, but since the specific gravity of the seeds is not over 1.4 they will wash out with the mud due to the velocity of flow of the water through the disintegrator. The coarser sand remaining in the tumbling barrel is seed-free, except for possibly some of the very large seeds which if present are easily picked out when the barrel is emptied. The coarser sands may be discarded.

(5) The overflow from the mill is passed over a 100-mesh screen, the material that passes through the screen going to waste. From one-half

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to two-thirds or more is eliminated at this stage. A 100-mesh screen is specified because with one or two rare exceptions all seeds are retained by a 100-mesh screen.

(6) The material remaining on the screen (and the sands remaining in the tumbling mill if so desired) are screened with a 10-mesh screen. The material remaining on the screen being coarse and free from mud is easily examined for seeds and can then be discarded. In some cases it may be possible to discard the sands from the mill after examination and without being screened through the 10-mesh screen, thus reducing the quantity to be treated later.

(7) The material through the 10-mesh screen is then washed on a reciprocating table of the Wilfley type, which eliminates all the heavier inorganic matter, the seeds being collected with the vegetable matter and some of the lighter inorganic substances.

(8) With a rich soil or one which has been fertilized with ash this last portion may be too large for convenient examination. A heavy liquid can be used to remove more of the vegetable matter and almost all of the remaining inorganic matter.

(9) The lighter fraction, now only a few ounces, may still be difficult to examine on account of the smallness of the particles. A further reduction in quantity may be made by passing the material through a set of differential rolls which will disintegrate the remaining humus without crushing the seeds.

(10) After passing through the rolls the material is screened through a 100-mesh screen to remove the fine humus.

(11) The remainder on the screen is then washed and dried for examination.

None of these processes takes very long; the whole operation can be completed in about three hours on a 15-pound sample of soil. Some steps of this operation may be eliminated for special cases such as the use of the washing table to remove sand from a swamp muck. Some soils consisting of loose fine sand might be fed directly to the washing table. As a whole, the method is applicable to practically every kind of soil that may contain seeds.

A QUANTITATIVE EXAMPLE OF A CONCENTRATION OF SEEDS

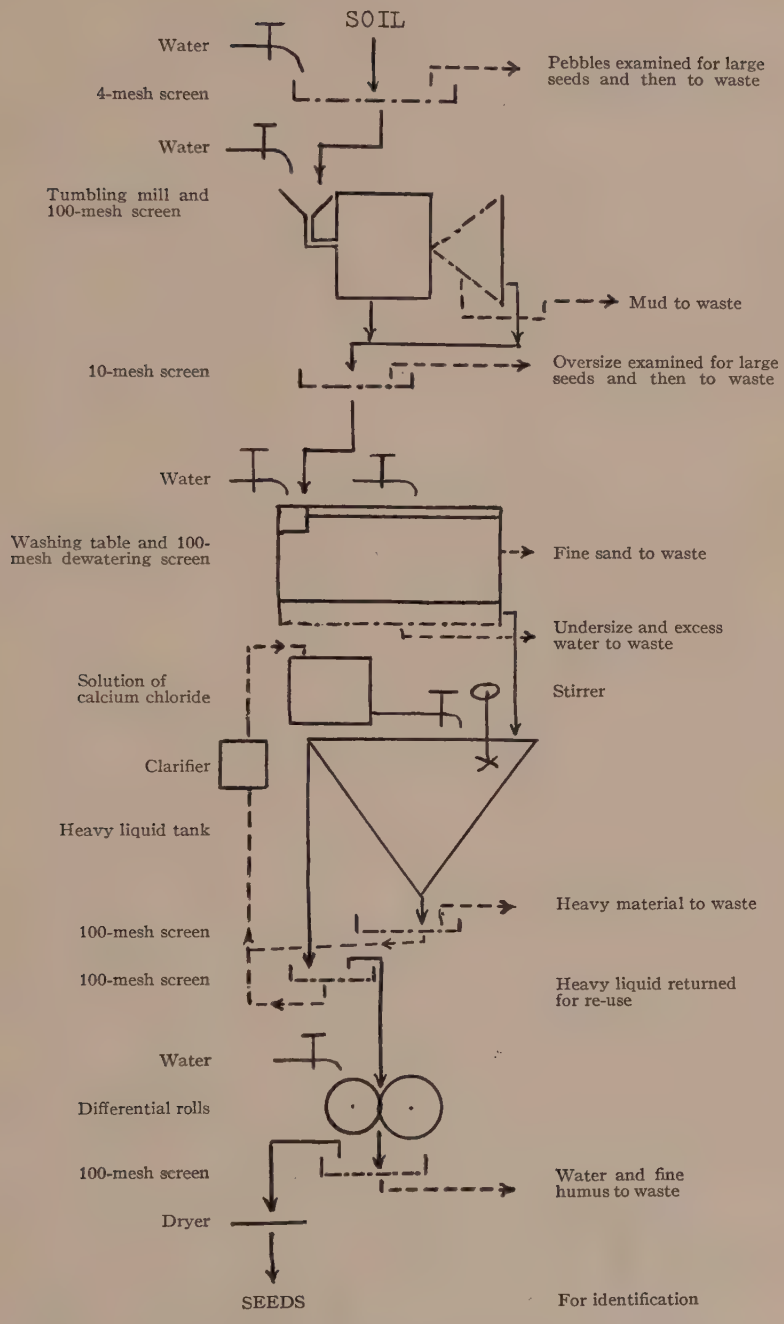
The material used in this test was a city garden soil which had been fertilized with household ashes and contained some of almost everything one could expect to find in soil (see Table 1). The soil as received was dry and in hard lumps.

TABLE 1

Materials	Weights
Original material (soil from a garden)	5840 grams = 100%
Pebbles separated on 4-mesh screen	None
Mud eliminated after disintegration	3808 grams = 65.0
Removed as +10-mesh material	253 grams = 4.3
Sand eliminated by the washing table	1036 grams = 17.7
*Eliminated by heavy liquid and rolls	736.4 grams = 12.6
Remaining seed concentrate	6.7 grams = 0.11

* This portion is unusually large because of the garden soil having been fertilized with ashes.

FLOW SHEET



The path of the seeds is shown by a solid line.

This complete flow sheet may be often simplified to suit particular soils by leaving out some of the steps of the process.

On careful examination the discarded portions showed a total absence of seeds. So that from an original weight of 12 lbs. 14 oz. the seeds were collected into a fraction weighing about $\frac{1}{5}$ of an ounce.

NOTES ON THE OPERATIONS

Preliminary Wetting

The circumstance that the soil may be received in a hard dry condition is no detriment to the separation of the seeds. The dryness might possibly be an advantage in that the seeds being dry would be harder and more resistant to any possible though unlikely subsequent damage. Several sprouted seeds from damp soil have been seen to go through the above separation process and be caught and identified.

The disintegrator or tumbling barrel is a revolving horizontal cylinder about 12 inches in diameter and 12 or more inches long. One end should be easily removable for emptying the mill. At one end is an inlet pipe for soil and water and at the centre of the other end a larger pipe for outlet. The R.P.M. is about 60. A mill this size can take an initial charge of about 5 lbs., and considerably more can be added with the wash water as disintegration proceeds. With an ordinary soft soil the effluent water will run clear in about 20 minutes, depending on the size of the soil sample. The grinding in this mill is negligible so far as seeds are concerned. After half an hour's tumbling, small earthworms and minute shells have been found in the sand apparently unharmed. The seeds cannot be harmed by the tumbling in the mill for they are washed out of the mill by the running water as soon as they are liberated from the clots of soil.

The slime screen of 100-mesh wire cloth to remove most of the mud may be a conical screen attached to and revolving with the mill. Water from a spray pipe may be used to help to keep the screen clean. A stationary screen blinds too easily with the fibrous organic matter and would have to be very large to give satisfactory screening.

The washing table does not require to be large. An ordinary laboratory sized Wilfley table about 2 ft. $\times$ 3 ft. is large enough. It is advisable to extend the thin end of the riffles to the table end in order to hold the sand well up on the table. Enough water is used to wash the seeds and organic matter over the lower side of the table. Unless the quantity of sand to be washed on the table is very large, the sand etc. can be fed to the table by hand, or if the quantity is very large, an automatic feeder of the belt type might be added. Or it might be possible to allow the plus 100-mesh overflow from the tumbling barrel screen to pass directly to the washing table and eliminate the 10-mesh screen. It would then be necessary to watch that none of the larger seeds passed away with the sands discarded from the washing table. An advantage in retaining the 10-mesh screen preliminary to the washing table is that it conveniently removes twigs, leaves, grass roots, etc. that would be a difficulty on the washing table and later.

The washings of light material can be caught in a screen bottom trough attached to the edge of the table. The motion of the screen with the large quantity of water keeps the screen from blinding and also gets rid of the unwanted wash water.

The removal of the seed from the heavier sand is very complete. Several lots of this waste sand have been tested with heavy solutions and by germination tests without finding a seed. Sometimes there may be present light specific gravity mineral matter that is perforce washed out with the vegetable matter and goes along with the seed. This would be unusual with a field soil but might be expected in a city or market garden soil because of the use of ashes as fertilizer.

The Heavy Solution

To make the heavy liquid, a solution of crude calcium chloride is satisfactory. The material used was made by the Bruner Mond Company, Amherstburg, Ontario, for putting on the roads. It is not very hygroscopic and can be stored without difficulty in the original paper-lined jute bags. It dissolves in cold water to a clear solution after time has been given for the extremely small air bubbles produced to rise to the top. The solution will acquire some discoloration with use but can be used repeatedly. It is also cheap.

The Heavy Solution Separation

The seed-carrying material from the washing table can be collected by a water jet into a suitable container and the excess water removed. This may be by drainage, by centrifuging or partial drying. It is not necessary for the material to be completely dried, for the principal reason for removing the water is to avoid diluting the heavy solution used in the next separation. Calcium chloride in water makes a convenient heavy solution.

Repeated trials have shown that the seeds of the various kinds listed below can be floated by a liquid of 1.370 specific gravity. This density will float every seed tested and will allow to sink almost all of the mineral matter and a considerable amount of the organic matter.

The seeds actually tested were: Wheat; oats; timothy; red, sweet and alsike clovers; alfalfa; nightflowering catchfly; bladder campion; white cockle; foxtail; ribgrass; field peppergrass; flea seed; lambsquarters; dock; fleabane; pigweed; cinquefoil; panic grass; sedge; stitchwort; mustard, and artemesia.

The effect of the heavy calcium chloride solution on the specific gravity of the seeds is negligible even after several hours soaking of the seeds in the solution.

In introducing the material to the heavy solution it is advisable to use agitation to break up clots so that seeds will not be trapped in the settling sands and organic matter.

The loss of heavy solution is small, for only a comparatively small quantity of material is to be treated, because of the previous removal of most of the waste soil.

One advantage of using a heavy solution for removing the last part of the mineral matter from the seed-containing material is the readiness with which, by diluting the solution to obtain other solutions of lesser specific gravities, a separation of the heavier seeds from the lighter ones can be made, thus aiding identification of the seeds.

It would be possible to use a heavy solution applied to the whole sample of soil, but it is not advisable, for disintegration would still be

necessary. A considerable quantity of liquid would be required, which would rapidly become useless, because of the taking up of the mud, making the solution thick and because of the increased amount of organic matter collected with the seeds.

The Differential Rolls

After the heavy solution has removed all possible material there will probably be considerable organic matter still with the seeds. By using differential rolls, the soft vegetable matter may be easily reduced in size so that it will pass a 100-mesh screen without at the same time breaking up the seeds.

The set of rolls consists of two rollers of different diameters, say 3 inches and 4 inches diameter, and about 12 inches long. Each roll face is covered with a piece of sponge rubber about $\frac{3}{8}$ of an inch thick. The rolls are geared together and spaced to exert a slight pressure at the line of contact.

When the rolls turn, the face of the larger roll travels at a slightly faster rate than the face of the smaller roll, giving rise to a slight rubbing action in the material as it passes through. Two rolls of the same diameter and different R.P.M. will give the same result. The rolls can be kept clean either by a water spray on the larger roll or by letting one roll dip into water. In operation, the feed is smeared on one roll so that it passes through the set of rolls only one seed deep.

This rolling does no damage to the seeds. A quantity of seed mixed with vegetable matter and some sand was passed through such a set of rolls over and over again until the set of rolls had torn to pieces everything it could. After eight passes the numbers of seeds recovered were the same as were started with at the beginning.

In another test, some sprouting seeds were passed through these rolls without being destroyed.

The length of time during which the seeds are wet in the preceding processes is so short that no appreciable extra softening of the seeds takes place whereby the gentle friction of the rolls could damage the seeds. The final operation is simply washing on a 100-mesh screen to remove the calcium chloride and then drying the seed ready for identification.

Flotation, as an alternative method of separating the seeds from soil, is not as good as the above method, though it is known that seeds are gathered in the froth of a flotation machine. The extraction is not positive and definite; some seeds being quite difficult to float. Flotation will not eliminate the primary processes of disintegration and screening to remove coarse mineral particles. The seed-carrying froth usually will also pick up fine sand and humus and require additional treatment. If the flotation is done by the usual laboratory machines the quantity of soil that may be treated at one time is limited.

The processes previously described and outlined on the accompanying flow sheet may easily be applied to a large quantity of soil thus allowing of good sampling of the original ground. The method is flexible; does not call for skilled operators; with ordinary care it is not subject to loss of seeds, and leaves the seeds in good condition for identification.

INEXPENSIVE SOIL SAMPLE PULVERIZER

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[Received for publication May 16, 1938]

PURPOSE

Most rapid soil test methods require a dry, fine product free of hard lumps, roots and stones. To do this with a glass rolling pin and hand sieve is very laborious and slow. The machine designed and described is capable of pulverizing lumps of soil containing stones up to three-quarters of an inch diameter, and removing all undesirable material from the fine sample in approximately one minute. The final product may be adjusted to pass through the desired sieve.

The total cost of the machine, including the motor, was less than ten dollars. With good care and proper adjustment, the life of the machine should be many years and maintenance negligible.

DESCRIPTION

The essential part of the pulverizer is an old clothes wringer, turned on its side and driven at about 100 RPM by a $\frac{1}{4}$ H.P. electric motor. To prevent the rollers from stopping as a stone passes through, an 18″ cast iron fly-wheel is attached directly to the roller shaft. This fly-wheel acts as a pulley from the motor, driven by a 1″ rubber belt. The motor pulley is about 1.2″ diameter. The soil sample is fed to these rollers by a wooden hopper, tin lined, which is fastened directly above it, and feeds to about the centre half of the rollers, through a $1\frac{3}{4}$″ to 1″ slit. The rollers, being old and rough, grab the lumps.

Coarse stones, roots, etc. are removed below the rollers by a $\frac{3}{8}$″ screen, mounted on a light wooden frame, which may be very easily removed for cleaning. A second tin hopper collects the finer material which passes through the screen and directs it through the centre two-thirds of a second set of rollers. These rollers are newer and smooth. As the course material passes through, the soil lumps are broken up, while the stones sink into the rubber and pass through unchanged. The mixture is collected on the final screen, which is surrounded by a suitable rectangular tin guide, and fits tightly but easily over the tin tray. Only slight shaking is required to separate the sample from the waste. The sample is ready for testing.

MATERIALS USED

One used clothes wringer from a machine, the running parts being in good condition, but the rollers badly scarred; wood frame.

One clothes wringer, new or used; wood frame type, preferably from a washing machine, and in good condition, having smooth rollers.

One fly-wheel pulley of cast iron, about 18″ diameter × 3″ rim, taken from an old farm side rake.

[1] Student Assistant.

One motor—quarter horse-power, washing machine type, used but in good condition.

Belting—1″ × 6′ of flat rubber with steel lacing.

Tin—1 sheet 20″ × 30″.

Screens—1′ × 1′ of meshes 3 and 12.

Lumber—1 piece $\frac{1}{2}$″ × $\frac{1}{2}$″ × 7′ dressed pine for screen frames; 1 piece 1″ × 6″ × 6′ d.p. for motor bed and top hopper; 1 piece 1″ × 3″ × 7′ d.p. for framework and legs of machine; 1 piece 3″ × 3″ × 1′ for turning pulleys (maple).

FIGURE 1

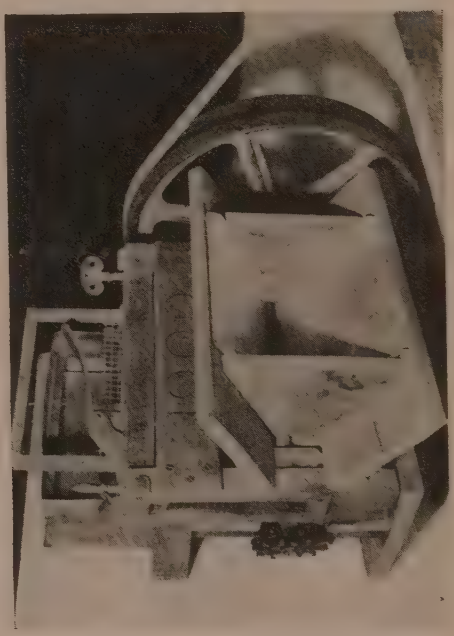
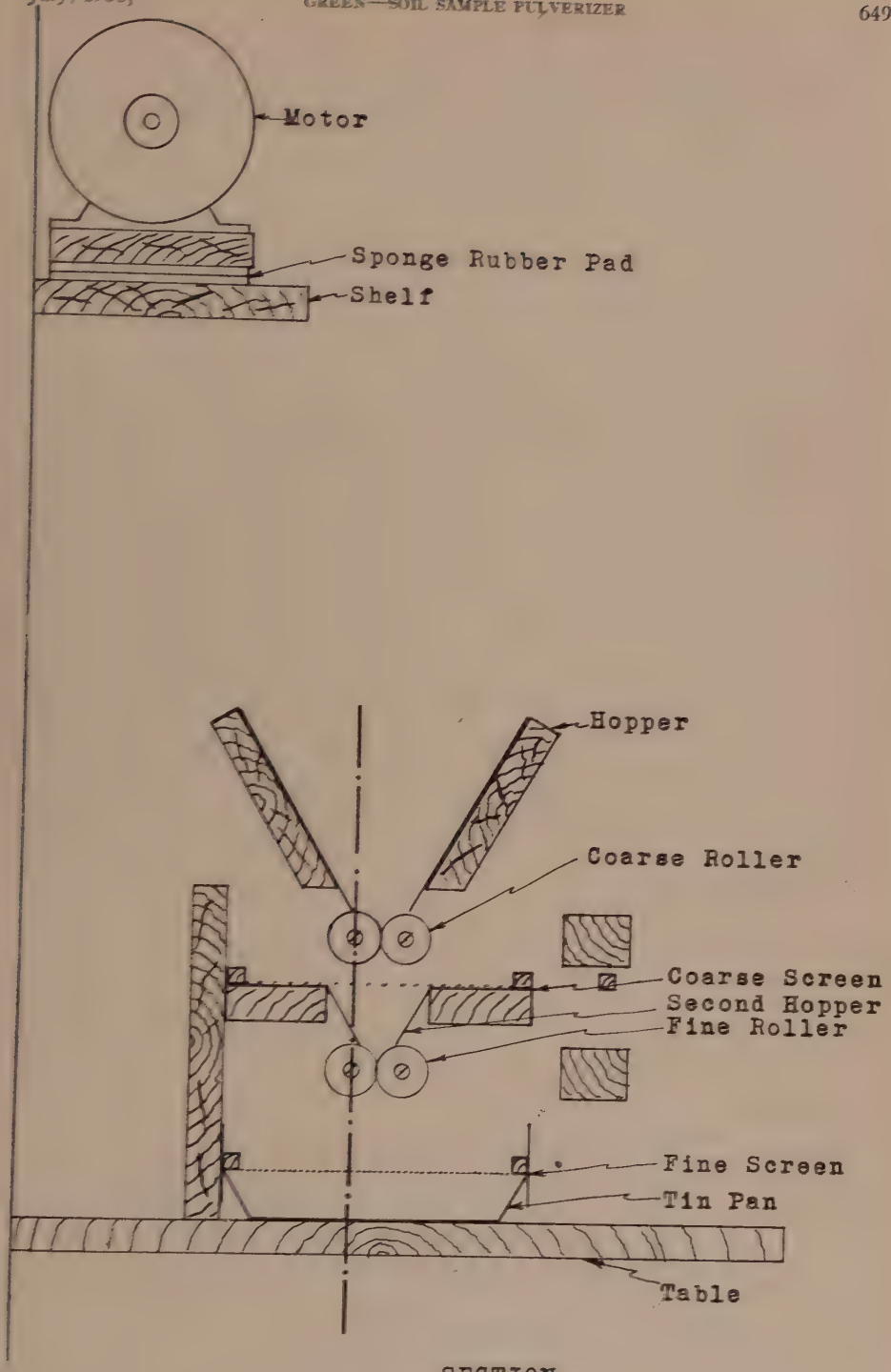


FIGURE 2

CONSTRUCTION

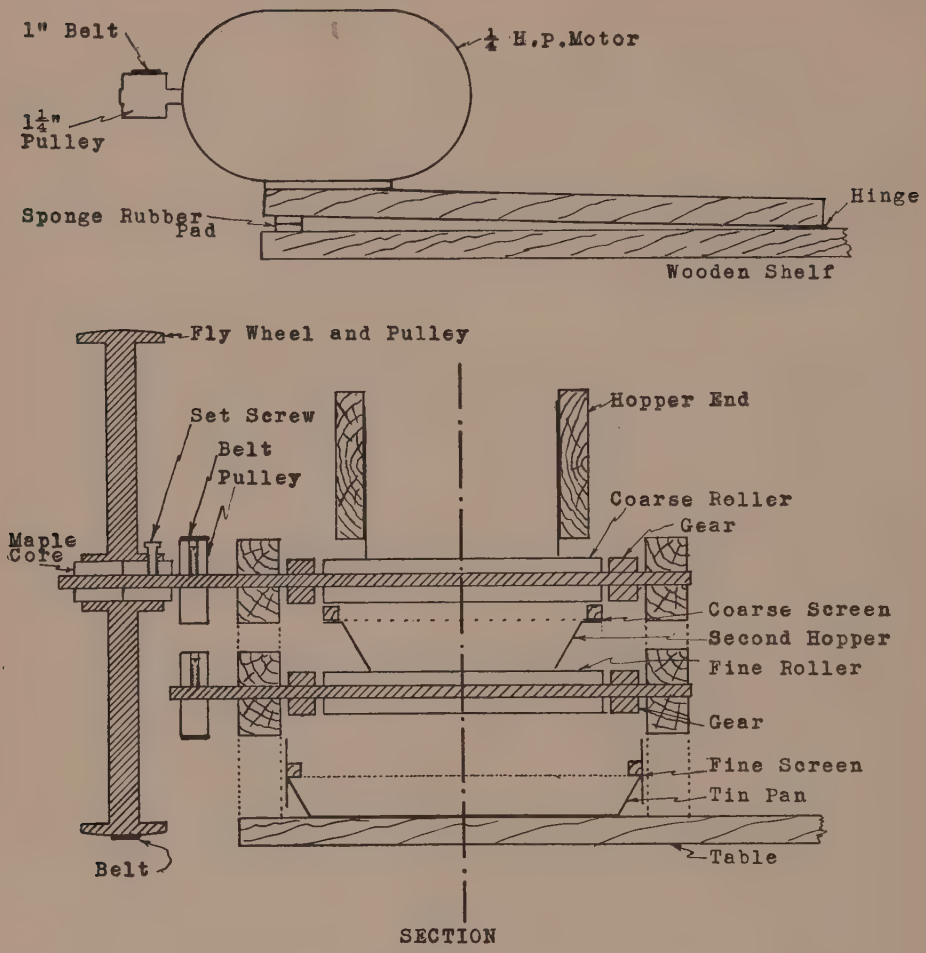
The pulleys were all made of maple. The motor pulley, 1$\frac{1}{2}$″ long and 1$\frac{1}{4}$″ diameter was made by first boring the hole for the motor shaft, and then clamping the block on a grinding arbor and turning down to the desired diameter. The centre of the pulley should be made with slightly greater diameter than the edges. This tends to keep the belt on. The finished pulley was fastened to the motor shaft by means of a set screw countersunk into the wooden pulley. The motor shaft had a flattened key way. The pulleys for the roller drive were made exactly the same way and about 1$\frac{1}{2}$″ wide by 3″ diameter. They were fastened to the shaft by means of set screws also. The shafts were filed slightly flat on one side to receive these screws. The fly-wheel was found to have about a 1$\frac{1}{4}$″ hole through the hub. A maple plug, drilled for the shaft as before, was turned, in two sections of the proper diameter and driven into each end of the hub. The hub of the wheel was drilled and tapped (at the machine shop) to take



SECTION

SOIL PULVERIZER

FIGURE 3



SOIL PULVERIZER

FIGURE 4

a $\frac{1}{4}'' \times 2''$ bolt, as a set screw. Again the shaft was filed flat to receive the set screw.

The main feed hopper was made of rugged wooden construction, so that any large lumps of soil might be broken up to pass through the machine. This was just a simple V box with vertical ends and tin lining. The side pieces were extended the full length of the frame, for support. The end blocks were placed about 2" from each end of the rollers. The hopper was lined with sheet tin, so that soil would not stick to it. The slot in the bottom of the hopper was about $1\frac{1}{2}''$ wide and 8" long and was placed as close to the rollers as possible. A second hopper of tin was built in, just above the second rollers to direct the soil into them. This was about 3" wide at the top, 1" wide at the bottom and 10" long at the top and 8" long at the bottom.

The wringers were stripped of all undesirable parts, such as the water directing boards and excess driving mechanism. The small pulleys were fastened onto the shafts and the wringers were ready for assembly. Two strips of wood, 1″ × 3″ were fastened to the top of the fine roller set (when horizontal). These supported the second hopper and extended the full length of the frame, lending rigidity. They were also bolted directly to the top roller set, which was placed on top. Four legs of 1″ × 3″ pine were now cut so as to leave about 3″ below the second rollers. These legs were firmly fastened to each side and to the back, by means of screws, into both coarse and fine roller frames. The total height of the machine is about 12″ without the hopper. The main feed hopper was then securely fastened in position by means of nails or screws into the ends of the coarse roller frame. Care was taken in placing all screws so as to leave the pressure adjustment free.

The top screen was tacked to a $\frac{1}{2}$″ × $\frac{1}{2}$″ wooden frame made to slide in just under the coarse rollers. The frame of the screen rested across the two 1″ × 3″ boards joining the frames of the rollers. The frame for the bottom screen was made to fit over the tin receiving pan. Tin strips, 2″ high, extended above and below the frame, forming a box, with a screen bottom and tin sides, which, when placed on the pan, fitted under the second fine rollers to collect the pulverized sample.

The motor was mounted on a shelf *above* the machine. This is very desirable since the motor bearings, which are of bronze, thus support part of the weight of the fly-wheel, which would cause excessive wear on the wooden wringer bearings and soon cause belt slipping and undesirable replacement and trouble. The motor was placed on pegs at the end of the 1″ × 6″ × 2′ board, which was hinged at the other end, as shown in the diagram, to the shelf. The board on which the motor stands is supported on the shelf by a pad (adjustable) of several layers of sponge rubber. This absorbs noise and vibration and provides a means of tightening the belt.

OPERATION

Due to the momentum of the flywheel and the method of drive, it is necessary to spin the wheel by hand, at the same time closing the switch, when starting the machine. However, with steady operation it is only necessary to do this occasionally and it is not inconvenient after a little practice.

Adjustment must be made for various types of soil, some requiring higher pressure to break them up. The pressure should be kept as low as possible, however, since this causes less strain on the machine. From time to time the belts tend to slip. The small belt may be tightened by wrapping a few turns of friction tape about one or both pulleys. This may be also used for the motor pulley. The long belt may also be tightened by increasing the sponge rubber pad under the motor.

Lubrication of all the bearings, including the motor, should be carried out about every hour of operation. This is very necessary since the soil dust soon causes rapid wear.

Feeding the sample is very simple after the machine has been properly adjusted. The sample may be just dumped into the hopper. Any large

lumps are easily broken up with a screw driver or other tool. As soon as the sample has all passed through the coarse rollers, the coarse screen is shaken vigorously, a few times. The material easily passes into the second rollers and is caught on the fine screen. The fine screen and pan assembly is removed and shaken vigorously until no more passes through. The coarse material on the screen is discarded and the sample in the pan may be further mixed by pouring back into the sample bag or box through a suitable funnel. The coarse screen need only be emptied after about 30 samples, or every half hour usually, but oftener if necessary. A small electric fan will carry all the dust away from the operator.

CONCLUSION

Over six hundred samples of soil, including both top and sub soils, were pulverized in the machine in an average of about one minute each. This saving in time alone would soon pay for the machine. With good care and proper adjustment, the time lost in breakdowns was almost negligible.

The design of mechanically shaken screens has been considered, but was soon discarded, since it is desirable to keep the machine as simple and as trouble-free as possible. A cover for the fine screen, to keep down the dust, has also been considered, but would mean another step in the operation, and would prove a nuisance.

The machine is a worthwhile addition to any soil laboratory, and should be a boon to rapid soil testing. It removes the drudgery and speeds the work of testing samples.

NUMBER OF SPECIES AS EVIDENCE OF PASTURE IMPROVEMENT[1]

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To secure the best quantitative botanical data in connection with pasture improvement investigations, careful and rather tedious quadrat readings are ordinarily relied upon. When, however, botanical surveys were sought in 1928 as a part of the Dominion Experimental Farms' study of continuous *versus* rotational grazing along with fertilizer applications, the best that could be offered immediately, in view of the time involved, was a simple reconnaissance listing of the species present. Such listings, notwithstanding other technique added later, have been continued each year at the 6 eastern stations concerned, for periods varying from 5 years at Charlottetown, P.E.I., to 10 years at Fredericton, N.B. The present paper proposes to examine what value, other than qualitative, was to be had from this minimum outlay of time. It leaves for another occasion all elaboration of the subject which might be based on developments from this original procedure.

Briefly stated, the procedure was to record the names of all species, useful or otherwise, in about the order in which they were detected in the course of zigzag progress from end to end of the field, omitting no part which might vary from the general character of the vegetation. Roughly the same time was allowed for each field of like area, about 7 or 8 minutes for an acre usually. Closely grazed pastures, requiring closer attention to vegetative characters for grass identification, claimed more time.

Obviously, even such a list of plants present in a field has more than qualitative value, for the order of listing is a distinct reflection of the abundance of the species. Those dominant are promptly recorded, while others present sparingly could only by chance secure as high a list position. A series of such lists from a check field presumably undergoing little change, would give a close approximation to an order of abundance which for important species could readily be given rough percentage value by means of visual estimate. Such order of abundance, as well as such estimate, might indeed come closer to bulk or production reality than is often obtained by either count or ground cover data. Only experience is advanced here in support of this position, which is supplementary only to the main contention under review.

Surveys could not be made at any uniform date from year to year, nor more than once annually at most stations. Nearly all were made during the months of June, July and August, and it is found that lists were about equal in length from any part of that period, although slightly shorter in June. Spring and fall lists may be expected to lack certain of the short-season plants, and to be somewhat shorter.

Lists from different stations that are spread across a thousand miles or so from east to west, and vary in climate, soil and otherwise, may be

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expected to vary in their species content. Different species, in part, and a different number of them are found at each point. The number is believed to be somewhat greater on the poorer and more acid soils, but it is clearly greater on the less stabilized pastures. The fields at Lennoxville and Ste. Anne were newly seeded for the experiment, and will be seen in the accompanying table to have lengthy lists of species; the fields at Ottawa and Nappan are old pastures, and give the shortest lists. The longer lists following tillage and re-seeding include, besides species introduced in the seed mixture, many weeds of arable land, mostly annuals, which tend to disappear as the land is compacted again, as well as the true pasture weeds, only temporarily checked by the breaking up of the previous turf. The short lists for old pastures, on the other hand, represent the survivors of a more or less drawn-out process of stabilization. Restriction of this study to one type from among these pastures would have some advantages, but to get the greatest possible volume of data they are all admitted, and the results from one type or all prove to be closely comparable.

NUMBER OF SPECIES IN SURVEY LISTS, 1928–1937, AVERAGED

—	Ottawa 1929–36	Lennoxville 1930–37	Ste. Anne de la Pocatiere 1930–37	Fredericton 1928–37	Nappan 1929–37	Charlottetown 1929–34	Ave. of six stations	—
Continuous grazing fertilized	17.5	43.0	42.0	34.2	22.4	34.2	32.2	Ave. of 57 lists
Continuous grazing unfertilized	20.7	52.3	41.6	48.4	31.7	39.0	39.5	Ave. of 52 lists
Rotational grazing fertilized	17.7	42.3	36.0	34.0	24.1	35.2	31.5	Ave. of 50X lists

In this table the two differentials of the experiment may be compared for each of the 6 stations, and for all stations together. It should be explained that each figure for rotational grazing is the average of 3 fields, or at Fredericton 4 fields except when occasionally fewer fields were taken as representative of those rotated. Also at Lennoxville separation of the two factors of the experiment provided an extra field continuously grazed and needing to be surveyed.

It will be seen from the average of the 6 stations that lists contain slightly fewer species with rotational than with continuous grazing, and distinctly the most without fertilizer. Observation, yield plots and animal gains are agreed in ascribing most improvement in these pastures to application of fertilizer, and to factors other than rotational grazing. Indeed, there has never been entire agreement among these various stations that rotational grazing materially helped. It is therefore of interest to note in which direction, though ever so slightly, this quite impersonal evidence points. It is shown, in any case, that application of fertilizer is followed by reduction of species in a pasture.

Evidence from phases of the surveys outside our present scope is ample to show that this reduction of species is of weedy species largely. Any exact distinction between weedy and useful species remains, however,

a matter of personal opinion, and is not here attempted. We may reasonably assume that the increase and invigoration of cultivated and other plants requiring the higher fertility levels is at the expense of weeds largely, which are opportunists present while the plant food, moisture and space are not fully pre-empted. Some weeds, like couch grass, dandelion, buttercup and plantain, are plants of rather high fertility levels, and being also strongly rooted, they persist well, but they are rather exceptions to the rule. The shallow-rooting hawkweeds and ox-eye daisy, the low growing species which are smothered by the thickening of the cover, and the annuals of arable land which survive for only a short time after seeding, are the majority whose wane and elimination with fertilizing is thus recorded. Some of the reduction of species, it is true, is to be attributed to the loss of sown grasses and legumes not fully winter-hardy, or, like red clover of short duration if prevented by grazing from reseeding, but such loss should be as great, if not greater, on the unfertilized fields.

It is not in the least the purpose to advance any new technique in place of current methods of securing ecological or grassland data, but it has seemed desirable to demonstrate that even the simplest reconnaissance listings, often the only surveys that time will allow, are capable of giving valuable information over a period of years. Such listings in sufficient numbers also give frequency indices which, though not equivalent to abundance, are indicative of it. Finally, visual estimates of percentage cover by each important species, add only a little more to the time required, and under the practised eye of the same observer from year to year, can secure a large part of the primary appraisal desired.

A FIELD STUDY OF THE FLIGHT, OVIPOSITION AND ESTABLISHMENT PERIODS IN THE LIFE CYCLE OF THE EUROPEAN CORN BORER, *PYRAUSTA NUBILALIS*, HBN., AND THE PHYSICAL FACTORS AFFECTING THEM

V. THE SEASONAL CHARACTERISTICS OF FLIGHT, OVIPOSITION AND LARVAL ESTABLISHMENT. THE VARIATIONS AND EFFECTS OF SEASONAL CLIMATE. THE FACTORS CAUSING FLUCTUATIONS IN BORER POPULATIONS. SUMMARY. ACKNOWLEDGMENTS

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Previously, the flight, oviposition and establishment periods have been dealt with as individual subjects. It is now proposed to consider the periods as seasonal entities; to show the part each plays in regulating the borer population and to discuss the physical factors affecting them as weather.

Review of the Literature

The literature concerning the abundance of the borer and its control by natural factors deals largely with yearly cycles and not with any particular season or insect stage, although Barber and Babcock have, as noted below, carried out researches on the effect of weather on egg laying and on the pupal period, respectively.

Barber (2) claimed that the cool nights of the year 1923 decreased the abundance of the borer in the New England area because the moths did not lay as many eggs as usual. The longer egg-laying season also increased egg parasitism.

Caffrey (4) gives a brief discussion of the climate experienced by the borer in its European habitats and compares the climates with those of certain American localities to which the borer may spread. No conclusion is reached, and flight, oviposition and establishment periods are not mentioned.

Babcock (1), upon whose work Caffrey's statements summarized above were made, discusses seasonal history in relation to various climates. He emphasizes the importance of the necessity of free moisture at the time of pupation. Flight, oviposition and establishment periods are not dealt with.

Thompson and Parker (10) consider the newly hatched corn borer larva a very delicate mechanism with highly restricted adaptive powers. Even in the most favoured environment and in the normal course of events, larvae undergo considerable mortality at the time of establishment. This apparently inherent weakness they term an intrinsic controlling factor. They point out that such factors are operative for other insects as well, and are probably far more important than realized in maintaining a natural equilibrium in insect species. Larval mortality, they state, varies under different conditions and is nearly always more important than that resulting

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from all other factors combined. They state that meteorological factors such as excessive heat or cold, extreme drought, drenching rains, or violent winds, if they occur at critical periods such as at the moment when young larvae are hatching or during periods of oviposition or during pupal period, may and undoubtedly do, cause a more or less heavy mortality, but unfortunately, little is known as to the part they play in the control of the borer.

Caesar (3) concluded from general observations and some experimental work that a very hot, dry season, especially in July and early August, is very unfavourable to the borer because of the mortality it causes among the newly hatched larvae. Hot, dry seasons also lessen the length of life of the adult, and hence the number of eggs. He concluded that between 1927 and 1930, in Ontario, the weather as a whole was unfavourable to the borer. Weather is so great a factor in control that in spite of the best practical clean-up of corn refuse, the borer may increase with ideal weather.

The seasonal variation in the number of eggs laid in 1929 and 1930 as observed by Flint (8) has already been discussed in part IV.

Caffrey and Worthley (5) determined that the percentage survival of larvae in 1931 was twice that of the drought year 1930. The next year the same authors (6) say that during 1930 a combination of deficient precipitation and excessively high temperatures during critical periods of the season were more adverse to the insect than for any season during the past 29 years. They point out that among the principal factors affecting the abundance in 1932 in Eastern United States were the more favourable weather for oviposition, a high larval survival and a large borer survival in corn refuse in the spring.

Davis (7) claims that the borer has not increased greatly in northern Indiana during the last 8 years because of unfavourable climatic conditions during the egg-laying and incubation periods, although other factors also may have been acting. He states that the years 1930, 1933 and 1934 were definitely unfavourable to the borer, 1932 not entirely favourable, and 1931 was favourable. His conception of dry, hot winds peeling egg masses from leaves has already been noted. According to Vance (11), the year 1936 was also unfavourable in Indiana and the borer population decreased.

Vance (11) attributes the decrease in the borer in eastern Indiana and the "thumb" section of Michigan in 1936 to the effect of lack of rainfall in the first half of July, supplemented by abnormally high temperatures prevalent during the second week of July.

In northwestern Ohio and southwestern Michigan, an increase in borer population occurred with a more favourable moisture distribution. This permitted an increase despite a pupal mortality of approximately 20% caused by excessive heat during the second week in July.

THE SEASONAL VARIATION IN MOTH POPULATION, REPRODUCTION AND SURVIVAL AT CHATHAM, ONTARIO.

Table 1 brings together for the first time data which have been presented during the progress of the paper. In this table the egg survival on plants is based on the number of eggs left on the plants after the mortality from dislodgement had taken place. Total egg survival is based upon the

total number of eggs laid. Larval survival is based upon the number of larvae hatching from eggs left after egg mortality had taken place, while total survival is based upon the total number of eggs laid.

TABLE 1.—THE SEASONAL VARIATIONS IN MOTH POPULATION, REPRODUCTION, SURVIVAL AND POPULATION INDEX, CHATHAM, ONTARIO, 1927 to 1936

Year	Total no. females in flight	No. eggs laid per female per 100 plants	Percentage egg survival			Percentage larval survival	Percentage total survival	Population index
			From dislodgement	On plants	Total			
1927	1431	4.9	—	—	—	—	—	—
1928	607	2.5	99.0	96.3	95.2	43.8	41.7	632
1929	104	7.6	93.4	98.0	91.4	18.1	16.5	130
1930	156	9.0	96.1	94.0	90.2	7.6	4.6	64
1931	66	5.1	97.4	92.3	89.8	57.2	51.4	173
1932	166	9.6	73.5	92.4	67.8	24.8	16.8	267
1933	224	6.8	88.3	94.4	83.2	21.1	17.6	271
1934	24	12.9	66.0	100.0	65.9	28.1	18.6	57
1935	23	15.2	86.4	91.9	79.2	48.7	38.6	134
1936	94	11.8	97.6	88.4	86.1	30.5	26.3	291
Average	289.5	8.5	88.7	94.2	83.2	27.9	23.9	224

The year 1928, with its high population index, was the most favourable for borer development, while 1934, with its very low population index was the worst year for borer development.

Population Index

The population index as used in this paper is a term devised to describe the resultant borer population secured from the measurement of seasonal female moth population, egg production, and total survival. It is really the number of larvae surviving from the total number of eggs laid on 100 plants by the female population of the season.

It may be expressed mathematically by the expression,

$$PI = (A \times B)C$$

Where PI = population index, A = the number of females in flight during the season, B = the number of eggs laid per female per 100 plants per season and C = the percentage of total survival. Total survival is the number of larvae, in percentage, surviving from the total number of eggs laid. It includes both egg and larval mortality.

Population index shows the result at the end of the season of adult and larval activity. The effect of all biotic and physical factors on the adult, egg and larval stage has taken place and their influence has modified the population index. The more favourable the season to borer development and increase, the higher will be the population index. The fluctuations in the magnitude of the population index will be shown later to have a very close correlation with the variations in the field population over wide areas, as expressed by percentage of stalk infestation.

It has been shown in Table 1 that some years have been definitely more favourable than others to the development of the corn borer. The table also shows for the various years at what point in the seasonal history of the insect the reduction or increase has taken place, whether it has been low moth population, low egg production, high egg mortality, either from dislodgement or in eggs remaining upon the plants, or because of high larval mortality.

Correlation of Borer Activity and Climatic Factors within Five-day Periods

To study the effects of the various physical factors on flight, oviposition and establishment, it is necessary to determine the time of the season these activities take place and then to evaluate the effect of the factors influencing them at the critical time. Seasonal occurrence and variations have been determined accurately and discussed at some length.

To study the effect of seasonal climate and the climate affecting definite periods, the season of flight, oviposition and establishment has been divided into eight, 5-day periods for each year. The percentage of the seasonal total of moths in flight, of eggs laid and of larvae hatching and other characteristics pertaining to the borer, are shown for each period in Tables 2 to 10. The average temperature, saturation deficiency, the number of rain showers and total rain are also indicated for each period.

The measurements of the physical factors were taken at the edge of the plots and constitute the records of a microclimate. Both temperature and saturation deficiency are based upon 12 bi-hourly readings for each 24 hours or 60 readings for the 5-day period.

TABLE 2.—BIOTIC AND CLIMATIC CHARACTERISTICS OF FLIGHT, OVIPOSITION AND ESTABLISHMENT SEASON, CHATHAM, ONTARIO, *1928*

Period		Average temp.	Average sat. def.	Rain		Per cent moths in flight	Per cent eggs laid	Per cent larvae hatching
No.	Dates			No. showers	Total rain, inches			
1	June 30–July 4	—	—	0.0	0.0	0.0	0.0	0.0
2	July 5–9	74.2	5.88	1.	0.33	3.7	4.0	0.0
3	July 10–14	66.9	4.05	3.	1.60	10.3	15.5	1.4
4	July 15–19	73.6	6.21	3.	0.18	41.5	44.6	11.3
5	July 20–24	73.3	4.55	3.	2.41	30.6	27.9	29.0
6	July 25–29	66.8	4.36	2.	0.07	6.5	6.5	42.7
7	July 30–Aug. 3	73.1	6.05	2.	0.11	5.4	0.0	12.9
8	Aug. 4–8	75.1	5.11	1.	0.53	0.4	1.1	0.0
Total				15.	5.23			

Total number of female moths in flight	607
Length of flight period in days	32
Number of eggs per female per 100 plants	2.5
Average number of eggs per mass	15.1
Per cent egg survival from dislodgement	99.0
Per cent egg survival on plants	96.3
Per cent total egg survival	95.2
Per cent larval survival	43.8
Per cent total survival	41.7
Population index	632

TABLE 3.—BIOTIC AND CLIMATIC CHARACTERISTICS OF FLIGHT, OVIPOSITION AND ESTABLISHMENT SEASON 1929, CHATHAM, ONTARIO

Period		Average temp.	Average sat. def.	Rain		Per cent moths in flight	Per cent eggs laid	Per cent larvae hatching
No.	Dates			No. showers	Total rain, inches			
1	June 30–July 4	66.1	5.82	3	0.57	0.9	*28.9	0.0
2	July 5–9	72.2	5.89	2	0.68	29.6	—	0.0
3	July 10–14	69.0	6.20	2	1.31	15.7	—	1.6
4	July 15–19	65.7	7.79	0	0.0	21.2	15.9	6.3
5	July 20–24	68.6	7.96	1	0.07	15.7	44.5	31.5
6	July 25–29	77.1	8.60	2	1.66	13.8	8.3	51.1
7	July 30–Aug. 3	68.2	7.53	0	0.0	2.7	2.2	6.2
8	Aug. 4–8	64.5	6.59	0	0.0	0.0	0.0	2.7
Total				10	4.29			

Total number female moths in flight	104
Length of flight period in days	28
Number of eggs laid per female per 100 plants	7.6
Average number of eggs per mass	14.6
Per cent egg survival from dislodgement	93.4
Per cent egg survival on plants	98.0
Per cent total egg survival	91.4
Per cent larval survival	18.1
Per cent total survival	16.5
Population index	130

* 28.9% of eggs were laid during periods 1–3, inclusive.

TABLE 4.—BIOTIC AND CLIMATIC CHARACTERISTICS OF FLIGHT, OVIPOSITION AND ESTABLISHMENT SEASON, 1930, CHATHAM, ONTARIO

Period		Average temp.	Average sat. def.	Rain		Per cent moths in flight	Per cent eggs laid	Per cent larvae hatching
No.	Dates			No. showers	Total rain, inches			
1	June 30–July 4	—	—	2	0.16	13.0	12.4	2.6
2	July 5–9	70.1	6.59	1	0.02	57.3	32.8	7.1
3	July 10–14	66.1	5.74	2	0.20	19.5	28.9	46.6
4	July 15–19	71.1	10.63	0	0.0	8.2	2.8	36.2
5	July 20–24	73.6	8.00	2	1.15	1.1	7.4	4.2
6	July 25–29	74.9	8.20	1	0.03	0	0	2.5
7	July 30–Aug. 3	73.0	10.69	0	0.0	0	0	0
8	Aug. 4–8	75.7	9.82	1	0.01	0	0	0
Total				9	1.57			

Total number female moths in flight	156
Length of flight period in days	26
Number of eggs laid per female per 100 plants	9.0
Average number of eggs per mass	16.6
Per cent egg survival from dislodgement	96.1
Per cent egg survival on plants	94.0
Per cent total egg survival	90.2
Per cent larval survival	7.6
Per cent total survival	4.6
Population index	64

TABLE 5.—BIOTIC AND CLIMATIC CHARACTERISTICS OF FLIGHT, OVIPOSITION AND ESTABLISHMENT SEASON, 1931, CHATHAM, ONTARIO

Period		Average temp.	Average sat. def.	Rain		Per cent moths in flight	Per cent eggs laid	Per cent larvae hatching
No.	Dates			No. showers	Total rain, inches			
1	June 30–July 4	79.4	9.01	0	0	12.5	11.0	0
2	July 5–9	72.0	7.07	2	1.50	31.9	30.0	0
3	July 10–14	69.6	7.57	0	0	34.7	14.1	34.8
4	July 15–19	76.4	6.53	1	0.85	20.8	13.2	7.7
5	July 20–24	70.6	5.58	3	0.81	0	21.6	22.0
6	July 25–29	77.6	9.56	1	T.	0	9.7	24.1
7	July 30–Aug. 3	73.7	7.31	0	0	0	0	10.8
8	Aug. 4–8	77.5	8.94	0	0	0	0	0
Total				7	3.16			

Total number female moths in flight	66
Length of flight period in days	20
Number of eggs laid per female per 100 plants	5.1
Average number of eggs per mass	12.7
Per cent egg survival from dislodgement	97.4
Per cent egg survival on plants	92.3
Per cent total egg survival	89.8
Per cent larval survival	57.2
Per cent total survival	51.4
Population index	173

TABLE 6.—BIOTIC AND CLIMATIC CHARACTERISTICS OF FLIGHT, OVIPOSITION AND ESTABLISHMENT SEASON, 1932, CHATHAM, ONTARIO

Period		Average temp.	Average sat. def.	Rain		Per cent moths in flight	Per cent eggs laid	Per cent larvae hatching
No.	Dates			No. showers	Total rain, inches			
1	June 30–July 4	66.8	6.73	3	0.89	0.5	4.1	0
2	July 5–9	67.7	5.35	1	0.35	34.1	17.4	4.0
3	July 10–14	70.5	6.13	2	1.20	36.2	31.0	6.4
4	July 15–19	77.3	6.44	0	0.00	17.8	30.4	13.6
5	July 20–24	72.2	5.74	1	0.53	5.6	1.1	57.7
6	July 25–29	68.7	4.28	3	1.40	0	7.5	7.6
7	July 30–Aug. 3	71.1	5.79	1	0.35	0	1.9	1.7
8	Aug. 4–8	71.5	6.77	3	0.58	0	0	8.4
Total				14	5.30			

Total number female moths in flight	166
Length of flight period in days	26
Number of eggs laid per female per 100 plants	9.6
Average number of eggs per mass	16.8
Per cent egg survival from dislodgement	73.5 (83.4)
Per cent egg survival on plants	92.4
Per cent total egg survival	67.8 (77.7)
Per cent larval survival	24.8
Per cent total survival	16.8 (19.2)
Population index	267

TABLE 7.—BIOTIC AND CLIMATIC CHARACTERISTICS OF FLIGHT, OVIPOSITION AND ESTABLISHMENT SEASON, 1933, CHATHAM, ONTARIO

Period		Average temp.	Average sat. def.	Rain		Per cent moths in flight	Per cent eggs laid	Per cent larvae hatching
No.	Dates			No. showers	Total rain, inches			
–	June 20–24	70.5	9.28	2	0.22	10.0	0	0
–	June 25–29	78.6	10.02	1	0.03	30.3	52.4	0
1	June 30–July 4	69.8	6.46	2	0.99	23.2	26.0	30.3
2	July 5–9	71.4	8.26	2	0.54	27.4	13.3	48.3
3	July 10–14	69.1	8.12	0	0.00	12.4	0	11.9
4	July 15–19	69.3	7.30	1	0.24	5.3	3.4	1.6
5	July 20–24	76.1	8.15	3	1.05	0.2	1.3	1.6
6	July 25–29	71.5	8.64	0	0.00	0	2.4	2.0
7	July 30–Aug. 3	75.3	8.95	1	2.00	0	0	2.5
8	Aug. 4–8	66.9	6.38	1	0.09	0	0	0
Totals				10 (13)	5.16 (4.91 in 8 periods)			

Total number female moths in flight	224
Length of flight period in days	27
Number of eggs laid per female per 100 plants	6.8
Average number of eggs per mass	15.1
Per cent egg survival from dislodgement	88.3
Per cent egg survival on plants	94.4
Per cent total egg survival	83.2
Per cent larval survival	21.1
Per cent total survival	17.6
Population index	271

TABLE 8.—BIOTIC AND CLIMATIC CHARACTERISTICS OF FLIGHT, OVIPOSITION AND ESTABLISHMENT SEASON, 1934, CHATHAM, ONTARIO

Period		Average temp.	Average sat. def.	Rain		Per cent moths in flight	Per cent eggs laid	Per cent larvae hatching
No.	Dates			No. showers	Total rain, inches			
1	June 30–July 4	74.9	11.51	0	0.0	29.2	11.8	0
2	July 5–9	69.8	5.93	3	0.37	17.0	11.8	0
3	July 10–14	75.5	6.58	3	0.47	29.2	44.4	25.7
4	July 15–19	71.8	8.63	1	0.08	17.0	31.8	14.6
5	July 20–24	78.7	11.81	1	0.03	4.8	0	59.5
6	July 25–29	72.4	8.87	1	0.38	0	0	0
7	July 30–Aug. 3	68.5	5.93	2	1.03	0	0	0
8	Aug. 4–8	69.5	6.93	1	1.17	0	0	0
Totals				12	3.53			

Total number female moths in flight	24
Length of flight period in days	25
Number of eggs laid per female per 100 plants	12.9
Average number of eggs per mass	17.9
Per cent egg survival from dislodgement	66.0
Per cent egg survival on plants	100.0
Per cent total egg survival	65.9
Per cent larval survival	28.1
Per cent total survival	18.6
Population index	57

TABLE 9.—BIOTIC AND CLIMATIC CHARACTERISTICS OF FLIGHT, OVIPOSITION AND ESTABLISHMENT SEASON, 1935, CHATHAM, ONTARIO

Period		Average temp.	Average sat. def.	Rain		Per cent moths in flight	Per cent eggs laid	Per cent larvae hatching
No.	Dates			No. showers	Total rain, inches			
1	June 30–July 4	72.2	6.01	0	0.0	0	0	0
2	July 5–9	74.7	5.61	3	0.18	10.3	0	0
3	July 10–14	76.5	8.63	0	0.0	44.8	33.3	0
4	July 15–19	70.7	6.22	2	0.78	37.9	22.1	7.2
5	July 20–24	77.0	5.26	3	0.33	6.8	31.2	42.6
6	July 25–29	71.3	6.05	1	0.22	0	4.8	33.5
7	July 30–Aug. 3	75.1	6.71	1	0.34	0	8.9	6.3
8	Aug. 4–8	72.4	5.01	3	0.86	0	0	10.0
Total				13	2.71			

Total number female moths in flight	23
Length of flight period in days	18
Number of eggs per female per 100 plants	15.2
Average number of eggs per mass	15.4
Per cent egg survival from dislodgement	86.4
Per cent egg survival on plants	91.9
Per cent total egg survival	79.2
Per cent larval survival	48.7
Per cent total survival	38.6
Population index	134

TABLE 10.—BIOTIC AND CLIMATIC CHARACTERISTICS OF FLIGHT, OVIPOSITION AND ESTABLISHMENT SEASON, 1936, CHATHAM, ONTARIO

Period		Average temp.	Average sat. def.	Rain		Per cent moths in flight	Per cent eggs laid	Per cent larvae hatching
No.	Dates			No. showers	Total rain, inches			
1	June 30–July 4	62.6	4.65	2	0.67	5.3	7.2	0
2	July 5–9	74.6	10.80	0	0	37.4	27.1	7.9
3	July 10–14	84.1	14.25	0	0	39.6	38.1	26.8
4	July 15–19	70.0	10.15	0	0	12.9	27.5	52.0
5	July 20–24	65.9	7.26	1	0.47	3.8	0	6.6
6	July 25–29	67.5	7.26	1	0.44	0	0	5.8
7	July 30–Aug. 3	67.7	8.87	0	0	0	0	0
8	Aug. 4–8	65.6	7.05	0	0	0	0	0
Total				4	1.58			

Total number female moths in flight	94
Length of flight period in days	27
Number of eggs per female per 100 plants	11.8
Average number of eggs per mass	15.5
Per cent egg survival from dislodgement	97.6
Per cent egg survival on plants	88.4
Per cent total egg survival	86.1
Per cent larval survival	30.5
Per cent total survival	26.3
Population index	291

59338—3½

A climatograph of the microclimate is given for each year in Figures 1 and 2. In the climatograph the average temperature is plotted against the average saturation deficiency for each period. The numbered points on the climatographs, instead of representing months as in an ordinary climatograph of a yearly climate, represent each 5-day period, the numbers and dates of which are shown on the tables. Rainfall is shown only in the tables.

The climatographs show the general character of each season and are directly comparable as to dates of each period. The variation in dates at which each insect stage is present is shown in the tables.

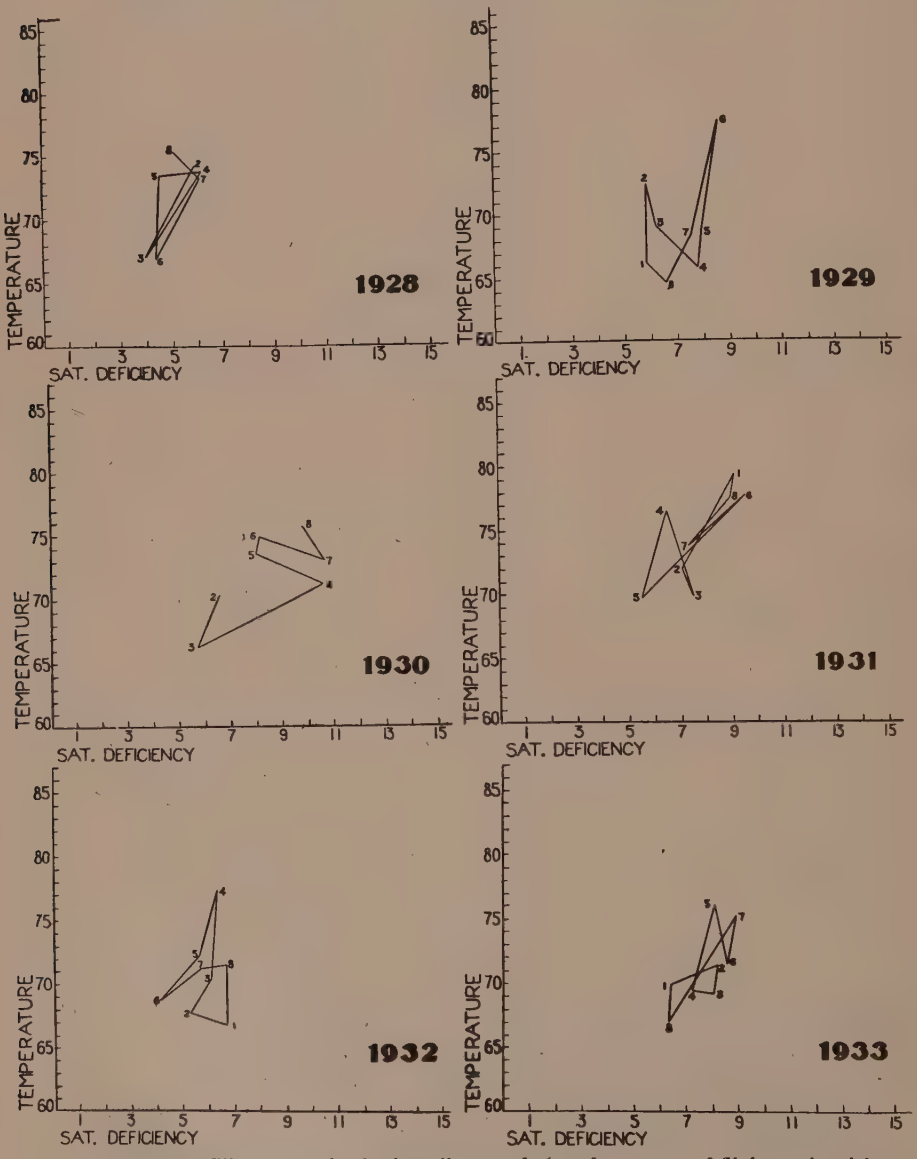

FIGURE 1. Climatograph of microclimate of plots for season of flight, oviposition and establishment, 1928 to 1933, Chatham, Ontario.

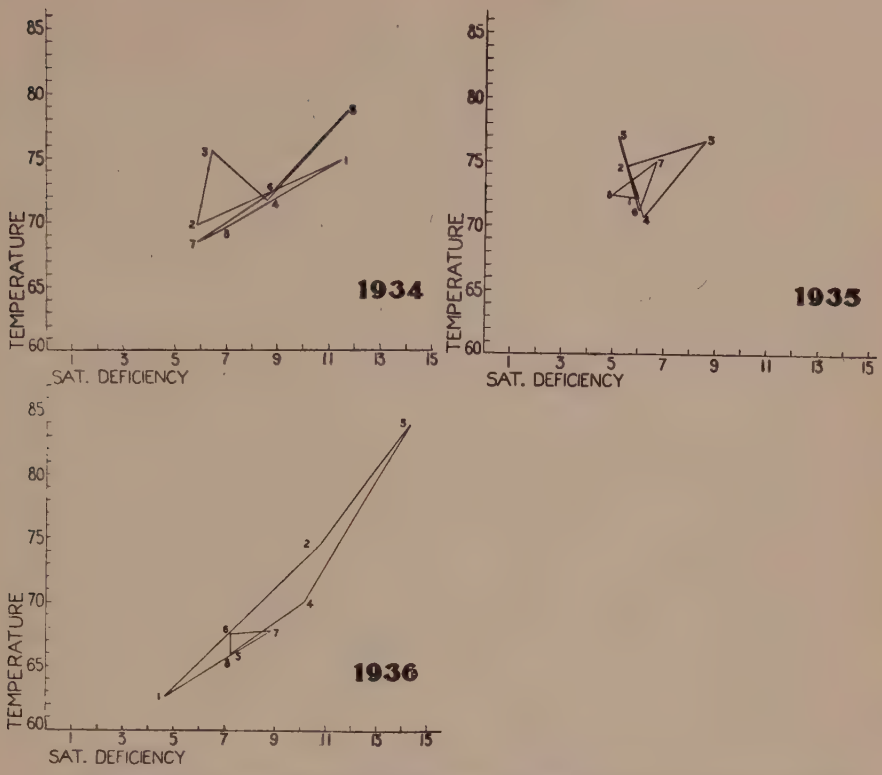

FIGURE 2. Climatograph of microclimate of plots for season of flight, oviposition and establishment, 1934 to 1936, Chatham, Ontario.

It has been shown that the incubation period has varied only slightly in duration in the years under study. The average duration has been 6.5 days. This means that the eggs indicated as being laid in each period in the tables will remain on the plants for about 6 days. Some eggs of each period will be on the plants in the period immediately following. This extension of the eggs into the next period has to be understood when determining the effect of weather upon them.

It has been shown, from a review of the literature, that larval mortality takes place immediately after hatching and within a period represented by the first 2 instars. The first 2 or 3 days after hatching determines the fate of the larvae. Any factors influencing their mortality will do so largely within the period in which they are known to have hatched. These periods are indicated in the tables.

Seasonal Characteristics of Moth Population, and Egg and Larval Survival

The most favourable year for borer development was 1928 because of the large initial moth population and the high egg and larval survival. It was the poorest year, of any, for egg laying. The flight period was the longest of any year, although about 70% of the moths flew in the two periods numbered 4 and 5. Egg laying was also largely confined to these periods, but most of the eggs hatched in periods 5 and 6. Periods 4 and 5

have an average temperature of about 74° F., with high humidity. Period 6 was much colder with about the same humidity.

Although 1928 was the best year for borer development of those studied, it was not the best year in the history of the borer in the region. This will be discussed later under population index and field infestations.

The year 1929 was below average in favourableness to the borer. This was largely because of the small numbers of moths in flight, but also because of the lowered total survival which was less than half that of the previous year. The lessened survival was largely confined to larval survival. The number of eggs per female increased about 5%.

The year 1930 had an available moth population of about one-quarter that of 1928 and about one-third more than that of 1929. Each female laid about 4 times as many eggs as in 1928 and about 2% more than in 1929. Egg survival was reduced about 5% from that of 1928 and about 1% from that of 1929. Larval survival was the lowest for any year, while total survival was also the lowest for any year, being only 4.6%. In spite of an increased moth population and more eggs per female the high larval mortality made 1930 a very unfavourable year for the borer. With its low survival, this year would have needed an initial population of about 1500 moths to give it the same population index as in 1928. The year 1930 was definitely unfavourable to the borer throughout western Ontario and a large section of the north central states. Caffrey (6) has already been quoted as saying the climate of this year was the most unfavourable of any in the last 29 years.

The year 1931 was below average in favourableness to the borer. The moth population was about one-ninth of that in 1928 and less than half of the population of 1930. Each female laid about twice as many eggs as in 1928, but only a little less than one-half of those laid by each female in 1930. Egg survival was about 5% lower than in 1928 and about the same as in 1930. Larval survival was the highest of any year, being 13% higher than in 1928 and 49.6% higher than in 1930. Caffrey (5) as already noted, says that in the northeastern United States survival was twice that of 1930. In our case, the survival was 10 times that of 1930.

The year 1932 had a moth population of a little less than one-fourth that of 1928 and about two and one-half times the number of 1931. Four times more eggs were laid per female than in 1928 and about double the number of 1931. Egg survival was low, being 27% below that of 1928, and 22% below that of 1931. The low egg survival was due largely to a local hail storm as already discussed. Larval survival was 21% lower than in 1928 and 32% lower than in 1931. The increase in the number of adults and increased egg production made 1932 above average in favourableness in spite of a marked decrease in egg and larval survival.

The year 1933 was slightly more favourable to borer development than was 1932. The moth population was slightly more than one-third of that of 1928 and increased about one-third over that of 1932. Each female laid a little less than 3 times as many eggs as in 1928, but only about one-third as many as in 1932. Egg survival was about 12% less than in 1928, but 15% more than in 1932. Larval survival was 22% less than in 1928, but only about 3% less than in 1932. The increase in the number

of adults present during this year was offset by the fewer number of eggs per moth and a decrease in larval survival.

The year 1934 was characterized by having a moth population one-twenty-fifth that of 1928 and only one-tenth that of 1933. Each female, however, laid 5 times as many eggs as in 1928 and about twice as many as in 1933. Egg survival was 29% less than in 1928 and 17% less than in 1933.

Egg mortality was confined to the egg masses being dislodged from the plants. Larval survival was 15% less than in 1928 and 7% more than in 1933. The low moth population, the poor egg survival and less than average larval survival made this the poorest year of any for the borer.

The year 1935 had a moth population of about one-twenty-fifth that of 1928 and practically the same population as in 1934. Each female laid 6 times as many eggs as in 1928 and approximately 3% more than in 1934. Egg survival was 24% less than in 1928 and 13% more than in 1934. Larval survival was 5% more than in 1928 and 20% more than in 1934. With the same moth population as in 1933, but with an increased egg production per female and an increase of 20% in survival, this year was over twice as favourable to the borer as was the year 1934.

The year 1936 had a moth population of a little more than one-sixth of that of 1928, but 4 times that of 1935. Each female laid about 5 times as many eggs as in 1928, but about 3% less than in 1935. Egg survival was 9% less than in 1928, but about 7% more than in 1935. Larval survival was 13% less than in 1928, and 18% less than in 1935. The greater moth population made it a better year for the borer in spite of an 18% decrease in larval survival.

Summary of Seasonal Characteristics

The variations in borer development in each year have been described and compared directly with the year 1928, which was the best year for development under study, and with the year previous. These variations will now be summarized.

A decrease in the borer population in 1929 was brought about largely because of a decrease in the available moth population, but also because of a very low larval survival.

Further reduction in population was brought about in 1930 by an extremely low larval survival. The moth population available for flight was larger than in the previous year.

An increase in population occurred in 1931 because of the extremely high larval survival. High survival caused an increase in population in spite of a greatly lowered moth population.

An increase in population occurred in 1932 because of a larger moth population and an increased number of eggs laid per female. These two factors overcame an adverse, low larval survival.

Population was increased in 1933 because of a larger available moth population when the survival was just a little below average.

A marked reduction in population occurred in 1934 because of a great reduction in moth population and a high egg mortality from dislodgement. This was the worst year of the 9 for borer development.

The borer population increased in 1935 because of greater egg production, a high egg survival and a high larval survival, while the moth population remained at the same level as in 1934.

The borer population increased in 1936 because of the greater moth population and to some extent the larger number of eggs laid per female. Egg and larval survival remained about average.

Biotic Factors Causing Seasonal Variation in Borer Population

It will be seen that the main biotic factors causing an increase or decrease in population in the summer season of flight, oviposition and establishment have been (A) the available moth population, (B) the larval survival, (C) the egg production per female and (D) the egg mortality.

Table 11 shows the biotic factor or factors responsible for a variation in the population during the years under study.

TABLE 11.—MAIN BIOTIC FACTORS CAUSING VARIATIONS IN BORER POPULATIONS FOR EACH YEAR, CHATHAM, ONTARIO, 1928-36

Year	Type of variation in population	Biotic factors causing variation
1929	Decrease	Moth population and larval survival
1930	Decrease	Larval survival
1931	Increase	Larval survival
1932	Increase	Moth population, egg production
1933	Increase	Moth population
1934	Decrease	Moth population, egg survival
1935	Increase	Egg production, larval survival
1936	Increase	Moth population

Moth population alone has been a deciding factor for 2 years in the increase or decrease in population. Moth population in combination with other biotic factors has been the deciding factor 3 other years. Larval survival alone has been the deciding factor in 2 years, while in combination with other factors it has been the deciding factor in 2 other years. Egg survival has been a factor in combination with moth population in 1 year. Egg production per female in combination with other factors has been the deciding factor in 2 years.

The important varying biotic factors in the summer season are available moth population and rate of larval survival or establishment. The physical factors affecting these will be discussed later.

Classification of Years According to Favourableness to Borer

As previously noted, and as shown in Table 1, the year 1928 was the most favourable year for borer development studied. As will be shown later, it appears that none of the years studied have been, on the whole,

entirely favourable to borer development. The years under study, however, have varied in their favourableness and may be classified.

TABLE 12.—A CLASSIFICATION OF YEARS ACCORDING TO FAVOURABLENESS TO BORER DEVELOPMENT, CHATHAM, ONTARIO, 1928–1936

Favourable year	Above average in favourableness	Below average in favourableness	Very unfavourable
1928	1932 1933 1936	1929 1931 1935	1930 1934

This classification is somewhat similar to that of Davis (7), supplemented by Vance (11), who show that in northern Indiana the years 1930, 1933, 1934 and 1936, were definitely unfavourable, 1932 was not entirely favourable, and that 1931 was favourable to borer development. The years 1933 and 1936 were more favourable in Ontario than they were in northern Indiana, while 1931 was possibly less favourable than in that region.

THE PHYSICAL FACTORS (CLIMATE) AFFECTING EGG AND LARVAL MORTALITY AND EGG PRODUCTION

Egg Mortality and Survival from Dislodgement

Survival from dislodgement has been uniformly high with an average survival for the 9 years of 88.7%. It was lowest in the year 1932 and 1934. These and other seasonal variations are shown in Table 1.

It has been shown previously that mortality from dislodgement in 1932 was due to a local hail storm.

The dislodgement of egg masses in 1934 will be discussed. In this year, egg production, because of the few moths in flight, was very low. In spite of the low egg production the year was peculiar on account of the high egg mortality from dislodgement. This was not only the case at Chatham, but it also occurred in other regions. Davis (7) as already pointed out, definitely noted that eggs were dislodged at a high rate during this year in northern Indiana.

Table 8 shows that 88% of the total eggs of the season were laid in periods 2, 3 and 4; 45% in period 3. The average weather conditions for these periods are shown graphically in Figure 2.

The dates on which egg masses were dislodged from plants during this year and for all other years have been shown previously. Two egg masses fell from the plants on July 13, 1934. This would indicate that conditions just previous to this date were conducive to the loosening of egg masses. This would be in period 3 on the climatograph, Figure 2, and in Table 8. This period shows an average temperature of 75.5° F.,

and a saturation deficiency of 6.58 mm., and three rain showers with 0.47 inches of rain. These average figures are not unlike other periods noted in which egg masses were not dislodged from the plants.

A more detailed survey of the weather, beginning on July 8, shows a series of hot days with cold nights as illustrated below:

Date	Maximum temperature	Minimum temperature
July 8	80	53
July 9	81	52
July 10	85	53
July 11	87	71
July 12	90	64
July 13	90	62

The humidity during the period was quite high as shown by the average saturation deficiency of 6.2 mm. It was not a hot, dry period.

The year 1934 is the only year of the 9 in which a period of hot days and very cold nights occurred during the time eggs were on the plants. This condition must have caused, directly or indirectly, the high egg mortality from dislodgement which took place in this year.

This conclusion is supported by the fact that a similar period of hot days and cool nights occurred in norther Indiana during 1934 when a high mortality, through dislodgement of egg masses, was noted by Ficht and Davis. G. A. Ficht of the Purdue Agricultural Experiment Station, has kindly supplied the weather records taken by him, in the field, at Auburn, Indiana, during the years 1932 to 1936. The year 1934 is the only one in which a period of hot days and cold nights occurred during the time egg masses were on the plants in numbers. The similarity of the period to that experienced at Chatham can be seen from the following maximum and minimum temperatures for certain dates at Auburn, Indiana:

Date	Maximum temperature	Minimum temperature
July 4	84	55
July 5	92	74
July 6	94	64
July 7	76	54
July 8	81	50
July 9	83	53
July 10	88	55
July 11	90	64

In other years at Auburn, Indiana, the lowest temperature recorded in any year was 60° F., and generally the minimum temperature was above this temperature. Here then, is an unusual period of hot days and cold nights occurring only in the year 1934 and at two widely separated localities. In both localities the year was noted for egg mortality from dislodgement.

The type of period just described would be one in which the leaves of the corn plants would be wilted during the daytime, but turgid at night. There would be considerable movement in the leaves of plants undergoing these changes. Huber (9) has already suggested such movements may have considerable influence in the dislodgement of egg masses. The type of period just described would also be conducive to the production of moisture on the surface of the leaves by guttation. The cool nights would retard evaporation from the leaves, but the soil, being warm, would favour absorption of water by the plant. The comparatively high humidity of the year would also reduce evaporation from the leaves. This effect would be quite marked as the humidity in this particular year was higher than in similar hot periods during other years.

There were no particularly heavy winds or heavy rain storms during the period the eggs were on the plants which could have caused a greater dislodgement of eggs during this year in comparison to that of other years.

It is suggested that the type of weather existing in 1934 between July 8 and July 13 caused egg masses to be dislodged from the leaves. The weather is characterized by cold nights and hot days, with comparatively high humidity. Such a season is conducive to the daily wilting of corn plants. The movements of the leaves during the process of wilting and in regaining turgor when combined with the production of abundant moisture through guttation are thought to be connected in some manner with the loosening of the egg masses from the plants, probably due to the physical forces operative in the process of wilting and again in regaining the turgor of foliage.

Mortality and Survival of Eggs Remaining upon the Plants

The survival of eggs remaining upon the plants has been relatively high in all years studied. The uniformity of the survival affords little opportunity to study the effects of varying weather conditions upon the mortality.

Effect of the Physical Factors upon Number of Eggs Laid per Female

The prohibitive and regulatory influence of temperature upon the flight of moths has been discussed in Part III and the effect directly upon the number of eggs laid per female per night has been discussed in Part IV. It was shown that the individual night temperature had no effect upon the number of eggs laid but that night temperatures considered as a season had a great effect. It is now proposed to discuss the effect of the seasonal temperatures acting for the entire daily period over the entire season.

The exact season in which moths were in flight has been shown in Tables 2 to 10. In Table 13 the average temperature and saturation deficiency, the number of rain showers and total rainfall are given for the period of the season when moths were active. From Table 13 it can be seen that the lowest number of eggs per female were laid during 1928.

TABLE 13.—THE RELATIONSHIP BETWEEN SEASONAL WEATHER DURING THE FLIGHT SEASON AND EGG PRODUCTION PER FEMALE, CHATHAM, ONTARIO, 1928–1936

Year	Average temp.	Average sat. def.	Rainfall		No. eggs laid per female per 100 plants per season	Length of flight period in days
			No. showers	Total rain, inches		
1928	71	5.3	9	3.92	2.5	32
1929	72	7.2	5	2.06	7.6	28
1930	69	7.5	5	0.38	9.0	26
1931	72	7.0	3	2.35	5.1	20
1932	72	5.9	3	1.55	9.6	26
1933	72	8.1	7	1.78	6.8	27
1934	73	8.1	7	0.92	12.9	25
1935	74	6.8	5	0.96	15.2	18
1936	76	11.8	0	0.00	11.8	27

This year was characterized by a low average temperature, the highest humidity of any year, the greatest number of showers, and the largest total rainfall of any year. As shown previously, this was a favourable year for borer development in every particular, except egg laying. A reference to Table 2 will show that the first portion of the egg laying season was particularly cool with an average temperature of 66.9° F. This was followed by a warmer period with an average temperature of 73.3° F. which, in turn, was followed by another cool period with an average temperature of 66.8° F. Humidity was high throughout the year. These low temperature periods lowered the egg production of the females in much the same manner as in the case reported by Barber (2) when low temperatures reduced the egg production of moths in New England in 1923.

It has been indicated in Part IV that the best years for egg production were 1934, 1935 and 1936. These years were the warmest and driest during the egg-laying period.

There is a slight indication that the conditions existing in 1935 during the flight of the moths approached the optimum conditions for egg laying. A decrease in egg production took place in 1936 when higher temperatures and a greater drying power of the atmosphere were experienced. A marked decrease also took place in egg production in 1934, with a lowering of the average temperature and an increase in the saturation deficiency.

From these studies it appears that the best season for egg laying is one in which the average temperature is about 74° F. and the saturation deficiency about 7 mm. Rain showers should be frequent, but light.

Eggs per female are reduced when the average temperature is 71° F., and the saturation deficiency about 5 mm., and when the rainfall is frequent and heavy.

Effect of the Physical Factors upon the Length of Flight Season

From Table 13, it may be seen that there does not appear to be a relationship between length of flight season and seasonal temperature and humidity. The year 1928 which had a low temperature and the lowest saturation deficiency of any year also had the longest flight season. The year 1927, as indicated in Part II, also had a long flight season of 31 days. This year also was cool and moist and quite similar in this respect to 1928. A comparison between the two years may be made by referring to Figures 2 and 3, in Part III. The hottest and driest years experienced, namely, 1934, 1935 and 1936, had flight seasons of about average length.

There is no indication that moths were killed by excessive heat or the excessive drying power of the atmosphere. This type of mortality has frequently been suggested, in the literature, as a factor in the natural control of the borer, but it apparently does not take place under natural conditions. If moths were killed, one would expect a shortening of the flight season in the driest and hottest years, but no such shortening of the season has occurred. Moths must have lived as long as usual during the hot year of 1934, as during it, large numbers of pupae were killed early in the season, thus reducing the supply of moths. The flight in this year was not shortened and the small number of moths originally available lived as long as usual.

Effect of the Physical Factors (Climate) upon Larval Mortality and Survival

The best opportunity to demonstrate the effect of the physical factors upon larval survival was to study the years in which extremes of mortality and survival occurred.

The year most favourable to larval survival was 1931. In this year, 57.2% of the larvae hatching were able to establish themselves and mature. Table 5 shows that 35% of the larvae hatched during period 3 between July 10 and July 14, while 46% hatched in periods 5 and 6, between July 20 and July 29. There were 2 principal hatching periods during the season. The first period as shown on the graph in Figure 1, was characterized by an average temperature of 69.6° F., and a saturation deficiency of 7.57 mm., and was rainless.

The second hatching period, in periods 5 and 6, was characterized by average temperatures of 70.6° and 77.6° F. respectively and average saturation deficiencies of 5.58 mm., and 9.56 mm., respectively. Four light rains occurred with a total rainfall of 0.81 inches.

The highest daily maximum temperatures occurring in the periods or between them, were on July 17 and July 29. On July 17, the temperature reached 91° F., with a saturation deficiency of 15.64 mm. The highest temperature on July 29 was 95° F. with a saturation deficiency of 22.26 mm. The rise to these high temperatures was quite gradual as is shown by the mean daily temperatures for each day between July 11 and July 17. These are as follows:— 67° F., 66° F., 69° F., 72° F., 73° F., 76° F., 78° F. A similar gradual rise occurred to the peak of July 29 during the second hatching period. To summarize: the period was characterized by a divided hatching season; temperatures were comparatively high during both periods, but the peaks in temperature were attained by a gradual rise in daily mean temperatures; humidity was neither high nor low, but was about average, showing a saturation deficiency of between 5 mm., and 9 mm.; no rains occurred in the first hatching period, but 4 light rains fell during the second period totalling 0.81 inches.

The year 1935 was also favourable for larval establishment as 48.7% of the larvae survived. The biotic and climatic characteristics of the year may be seen from Table 9 and Figure 2. Seventy-six per cent of the larvae hatched in periods 5 and 6 between July 20 and 29. These periods had an average temperature of 77° F., and 71.3° F. respectively. The humidity was a little higher than average, the saturation deficiency being 5.26 mm., and 6.05 mm., respectively. Four rain showers occurred, giving a total of 0.55 inches of rain. The highest daily temperature experienced was 89° F., with a saturation deficiency of only 16.07 mm. No very great fluctuations in temperatures occurred during the periods. It was a comparatively uniform warm period, with humidity above the average level.

The year having the highest larval mortality and therefore the lowest survival was 1930. In this year, only 7.6% of the larvae survived. The biotic and climatic characteristics of the year are shown in Table 4 and in Figure 1. About 83% of the larvae hatched in periods 3 and 4, between July 10 and July 19. Period 3 was characterized by a low average temperature of 66.1° F., and a fairly high humidity, while period 4 had a higher but still low average temperature of 71.1° F. and a fairly low humid-

ity as shown by the average saturation deficiency of 10.63 mm. The drying power of the air was twice as great in the last period as it was in the first.

The hatching season was characterized by a comparatively cool, moist period, suddenly turning into a hot, dry period. This is shown by the average daily temperatures between July 10 and July 19, and which follow: 68° F., 69° F., 66° F., 70° F., 56° F., 58° F., 64° F., 73° F., 80° F., 80° F. The lowest actual temperature was 44° F., with a saturation deficiency of 1.48 mm., which occurred on July 14. The highest actual temperature occurred on July 18 when the maximum was 94° F., with a saturation deficiency of 31.06 mm. Two light rains, totalling 0.20 inches, occurred during period 3, but there was no rain during period 4.

The sudden hot spell or heat wave is reflected in the night temperatures charted for moth flight studies shown in Figure 5, Part III.

If high temperatures and low humidities, either alone or in combination cause larval mortality, by far the greatest mortality should have occurred in the year 1936 as this was the hottest and driest year on record during the time larvae were hatching. The larval survival for the year was 30.5% which is above the average survival for the 9 years.

The biotic and climatic characteristics of 1936 are given in Table 10 and in Figure 2. In this year, 80% of the larvae hatched in periods 3 and 4, or between the dates of July 10 and July 19. Period 3 is characterized by an average temperature of 84.1° F., and an average saturation deficiency of 14.25 mm. The atmosphere under these conditions was not only on the average, much warmer than during the previous years discussed, but its drying power was greatly increased, being twice as great as in 1931, over twice as great as in 1935, and considerably increased over that of the period 2 in 1930 when so many of the larvae were destroyed. The very high average temperature and high saturation deficiency of period 3 is shown strikingly in the climatograph in Figure 2. Period 4 was characterized by an average temperature of 70° F., and a saturation deficiency of 10.15 mm. There was no rain during either period.

There was a period of consistently high temperatures and low humidities until near the middle of period 4 when the temperature dropped. This decrease in temperature, however, came too late to influence survival as the larvae were already established. Temperatures as high as 102° F. with a saturation deficiency of 30.10 mm. were experienced during the heat wave.

From the above observations, it is concluded that variations in larval mortality and survival are brought about mainly by the destruction of larvae by very sudden changes in temperature. In 1930, the annual average survival of 27.9% was reduced to a survival of only 7.6% by a sudden heat wave during the season of hatching. The very hot, dry season of 1936 did not affect larval survival, and in the comparatively cool, high humidity year of 1928 the survival was much greater than usual. Sudden variations in temperature, even if at a comparatively high humidity, caused larval mortality. This conception has never before been advanced. Most authors deal with the subject in a general manner and attribute larval mortality to a number of factors, but mainly to hot, dry periods, or to winds or rains throughout the entire season.

The detrimental effect of rain upon larval establishment is overestimated in the literature. During the year 1931, in which larval establishment was highest, the hatching larvae were subjected to 4 rain storms. In 1935, the year in which the second highest survival took place, 4 rain storms were experienced during hatching. In 1928, the year in which the third highest rate of survival was found, there were 13 rain storms during the entire season, 5 of them taking place during the establishment period. In period 5, when 29% of the larval population hatched, the rain amounted to 2.41 inches within 4 days. In spite of this large amount of rain, larval survival was 43.8%. Rain storms do not influence larval survival to any appreciable extent.

Population Index and Field Infestations

The seasonal variations in borer populations obtained by plot study, and shown by the population index, bear considerable relationship to variations in field populations in wide areas. This relationship is shown in Table 14.

Table 14.—Population index and field infestation in Kent county and in husking corn region of southern Ontario, 1924–1936

Year	Population index	Per cent stalk infestation Kent county	Per cent stalk infestation husking corn area
1924	—	24	18
1925	*6927	53	31
1926	*7076	79	65
1927	*1682	47	49
1928	632	38	33
1929	130	26	30
1930	64	21	16
1931	173	27	22
1932	267	27	24
1933	271	35	29
1934	57	8	8
1935	134	24	22
1936	291	20	24

* The population index for these years is a theoretical value calculated as described in text.

The population index for the years 1925, 1926 and 1927 is theoretical and based upon the following data. For the years 1925 and 1926 the total number of eggs laid per 100 plants per season as found by Ficht and presented in Part IV, is divided by the average number of eggs laid per female as found during the years 1927 to 1936 to determine the number of females in flight. The population index is then determined by the method evolved and presented previously, using the necessary average values as determined during the years 1927 to 1936 and presented in Table 1. In 1927, the moth population and eggs per female have been measured and presented. For this year, the average percentage of total survival as found during 1928 to 1936 was used for the calculation of the population index.

The husking corn area, as used in the table, is constituted by the counties of Essex, Kent and Lambton. The stalk infestation for this area is much lower than for Kent county alone during the year 1924 and 1925 because Essex and Lambton counties were not yet fully infested or, if infested, the borer population was still quite low.

The percentage of stalk infestation has been compiled from records taken by the Provincial Entomologist of the Ontario Department of

Agriculture, and the Entomological Branch of the Dominion Department of Agriculture. The records are based upon determinations made on 300 stalks in each of, at least 40 fields per county in each year.

It is seen from Table 14 that, with the exceptions of the years 1932 and 1936 in Kent county, an increase or decrease in the population index foretells an increase or decrease in the field population in large areas. Even in 1932 and 1936 in the larger area, the trend is shown.

Population index does not show the rate of variations in the larger areas, but it does show population trend in each year.

Factors Causing Fluctuations in Field Populations

From the fact that field study plots located in the centre of Kent county, show the trend of borer population in wide areas, it may be adduced that the factors causing the variations are acting over wide areas and whole districts instead of being limited to small areas. It has just been shown by plot study that temperature, when in the form of sudden heat waves, causes high larval mortality, and that alternating very cold nights and hot days cause the egg masses to be dislodged from the plants. It has also been shown that rains have little or no effect on larval survival. These conclusions seem to be verified by the close relationship between study plots and field infestation, as temperature and, perhaps, humidity conditions are usually more uniform over large areas than are either rainfall or wind.

The factors responsible for the increase or decrease in borer population for the years 1929 to 1936 have been enumerated and discussed above. Although outside of the province of the present paper, something might be added regarding the decreases in population in the years 1927 to 1928.

The importance of initial moth population has already been shown and the importance of pupal mortality in this connection has been discussed in Part II. It has been shown that in the year 1934, a high pupal mortality occurred because a hot, dry period killed the pupae just before emergence. It is almost certain that pupal mortality is partly responsible for the large reductions in borer populations during the years 1927 and 1928. A very close and detailed survey of weather records reveals the fact that these years are the only ones, other than 1934, which experienced a similar hot, dry period during the time pupae were in the fields in numbers.

There was a comparable period in 1925, but it occurred between July 10 and July 15, which would be too late for pupae as they would have emerged by these dates. In 1926, there was a hot period of three days between July 8 and July 10 which was accompanied by rain. The hot, dry period of 1927 took place between June 28 and July 3. The average daily temperatures ranged from 68° F., to 84° F. with no rain between June 21, and July 2.

In 1928, the period was longer, extending from July 2 to July 11. The average daily temperatures ranged from 71.5° F. to 80.5° F. There was no rain until July 9. In the other years, from 1928 to 1934, there was no hot, dry period between June 15 and July 15, except in 1931. In this year, there was a very hot period just at the time of pupation, but it was accompanied by frequent rains.

Corn Refuse Clean-up and Population Variations

The enforced corn refuse clean-up administered by the Ontario Department of Agriculture was also a factor in reducing initial moth population in the years 1927, 1928 and subsequent years. The clean-up was first carried out in 1926 and the crop of 1927 was the first to benefit from it.

The importance of initial population and pupal mortality as a factor influencing this population has been brought to greater prominence in the present paper. This also further emphasizes the great importance of the corn refuse clean-up as a method of reducing initial population. The clean-up is of added importance as through it the corn stalks are worked in such a manner that at the completion of operations, the refuse left is lying prone on the soil surface, and if a hot, dry period does occur, the pupae are more certain to be killed than if the stalks were standing.

SUMMARY

A detailed quantitative study of the flight, oviposition and larval establishment periods in the life cycle of the European corn borer, *Pyrausta nubilalis* Hbn., and the physical factors affecting them has been made at Chatham, Ontario, Canada, during the years 1927 to 1936.

The methods of study have been outlined in some detail because of the quantitative methodical field treatment involved, and because some of the features of the study are a new approach to a field problem.

The seasonal limits of the flight period have been found to be on the average from July 1 to July 27, with the peak of flight usually taking place about July 9. The length of the flight season has averaged 26 days, but moths are usually absent for about 6 days during each season which would give an actual flight season of about 20 days. Moths were caught in the light trap earlier and later in the season than they were in the corn field, but the peaks of flight to corn and to light trap occur about the same period. Very late seasonal captures in the light trap have indicated the presence of a very small second generation of the borer in some years.

The largest flight occurred during the season of 1927 and the smallest during 1935, when only 29 moths were observed in the plot. Flight to light trap is of greater magnitude than that to the corn field during some years, while in others it is smaller.

In corn fields, the average percentage of males in flight has been 15.5. It has varied from 41% in 1934 to none in the years 1927 and 1928. The light trap catches, on the other hand, have averaged 74.7% males.

The protrandric tendency of males to emerge from the pupae before the time of emergence of the females is not carried over into the period of flight in the corn field. Males do not appear in the field before the females.

There is a period of a few days between emergence in the region and the flight of the moths to corn fields. The length of the period is longer than that of the preoviposition period. In some measure, the non-appearance of moths in the corn field for a considerable time after emergence might be explained by the fact that the males emerge from the pupae in greater numbers earlier than do the females.

Flight takes place each favourable night beginning about ½ hour before sunset. Moths continue in flight in numbers until about 3½ hours after sunset. Only about 2.7% of the moths fly after 4:30 Sunset time; 94.7%

of the moths fly between ½ and 4½ hours after sunset, while 79.4% fly in the shorter period between ½ hour and 2½ hours after sunset. The period of flight is quite definite year after year. No sexual differences in the time of night of flight were noted.

The general subject of the time of activity of nocturnal insects has been discussed. The corn borer moth flies at the same period of the night as do certain other Lepidoptera, but the literature upon the subject is not extensive. Most of the studies, upon the time of night of the activity of nocturnal insects, are based upon captures in light traps. In the present study, measurements of flight activity have been secured of the actual flight, over plots of the host plant of the insect and are therefore, possibly of more value in that they are truer to actual conditions. The biological question as to why insects fly at night and usually at definite periods, although constantly in mind, has not been answered in the case of the corn borer. Some light on the subject was sought in the correlation of temperature, humidity, atmospheric pressure and time of sunset, with the appearance of the first moth each night, but no correlation with any of these factors was found.

The value of light traps in the study of the biology and periodicity in insects has been discussed. It is shown that no relationship exists between the magnitude of flight in the corn field and that indicated by light trap catches. The seasonal abundance of the borer cannot be judged by the attraction of adults to light traps. This conclusion supports that of Cook, who found that the capture of noctuid moths in a light trap is not a reliable index upon which to judge the numbers present within a given season. The present work demonstrated that the light trap is a better measure to determine the seasonal limits of flight than is any individual corn field.

The value of using Sunset time in the study of flight activities of nocturnal insects has been pointed out. Sunset time allows a direct comparison to be made of the times of activity of insects and with more accuracy than if civil time was used.

The optimum temperature for flight was found to be between 65° F. and 70° F. The lowest temperature at which flight was observed was 56° F., but generally flight is terminated at 58° F., or 59° F. Low temperatures prohibit flight much more quickly than do high temperatures. A lowering of the temperature from 65° F. reacts more quickly on flight activities than does a rise from 75° F.

There is a positive relationship between temperature and flight activities. Temperature on individual nights regulates moth flight. A rise in temperature causes an increase in the numbers of moths in flight and a decrease in temperature causes a decrease in number or if low enough, a cessation.

The optimum temperatures and other relationships in the corn borer are very close to those found by other authors for codling moth and bud moth.

Average seasonal temperatures apparently have no regulative action on the duration of the flight season as has been suggested in the literature. The flight season was longest in the 2 years with the lowest average tem-

peratures, but in all other cases, seasonal temperature did not affect the length of flight season. The shortest period did not occur in the hottest and driest season.

It is demonstrated that during the 10-year period, most moths flew at high humidities. Ninety per cent of the moths flew at humidities indicated by saturation deficiencies of 0 mm. to 6 mm. No correlation, however, could be found between moth flight and humidity on individual nights. The influence of temperature is so great that any effect of humidity is masked.

Wind, at velocities at least up to 17 miles per hour, has no effect upon flight. This was the highest velocity experienced during the 10-years' observations. Rain, on the other hand, will prohibit flight if heavy enough. Rain at the rate of 0.14 inches an hour usually prohibits flight. Moths will fly in light rains.

The effect of the electrical state of the atmosphere during and immediately after thunder storms was observed, but the results are conflicting. In one case, adults flew immediately after the storm and in another case they did not fly for at least 2 hours.

It has been shown that lunar periodicity does not influence the time of occurrence of the annual flight cycle or that of daily rhythm.

Atmospheric pressure, within nightly periods or for longer intervals, does not influence flight. The same is true also of mists or fogs, and cloudiness.

Moisture in the form of dew and guttation has been considered from the viewpoint of the necessity of water for the normal life of the adult, but no relationship with insect activity could be found. Water of guttation usually appears before dew, and in some cases dew does not appear and water from guttation is the only moisture present.

The egg laying season, naturally, follows that of flight, but there is a difference in the rate of development of peaks in different years. In some seasons, conditions are earlier more favourable to egg laying than they are to flight and *vice versa*.

The number of eggs laid per female per 100 plants per season has averaged 8.5. The poorest years for egg laying were 1927 and 1928, and the best years were 1934, 1935 and 1936. The first 2 years were the coolest and wettest experienced, while the second group were the hottest and, on the whole, the driest years. Temperatures on individual nights did not influence the number of eggs laid per female per night. Ninety-four per cent of the eggs are laid on the lower surface of the leaves 5% on the upper surface and 0.5% on the culm.

Egg mortality has averaged 16.8%, thus giving an average survival of 83.2%. Mortality from dislodgement of egg masses from the plants has averaged 11.3%, while in one year, 1934, it amounted to 34%. Increased mortality above the average through dislodgement is due to a series of alternate hot days and cold nights. In 1934, the series of days causing dislodgement consisted of those having a maximum temperature of 90° F., with a minimum temperature of 52° F. The humidity at the time was fairly high, the average saturation deficiency being 6.2 mm. It is suggested that during such a period of weather the egg masses are mechanically

loosened from the leaves by the alternate wilted and turgid condition of the leaves during the daily cycle. This type of weather is also conducive to heavy guttation and this might also help loosen the egg masses. Formerly, it was thought that egg masses were dislodged by the action of heat and desiccation during hot, dry periods. Egg masses were not dislodged at Chatham during continued hot, dry periods.

The mortality of eggs remaining upon the leaves is consistently low, averaging 5.8%. Because of the uniformly low mortality, it was impossible to learn anything about the factors causing this mortality in the field. It was not due to parasites or predators.

Egg masses laid on the upper surface had about the same mortality rate as those laid on the under surface of the leaf. Other authors have reported a high mortality in eggs placed on the upper surface of the leaves.

Larval mortality in establishment was found to average 72.1%, or a survival of 27.9%. It varied from a survival of 57.2% in 1931 to as low as 7.6% in 1930. Increased larval mortality is caused by sudden heat waves and is independent of humidity. In 1930, the mean daily temperature rose from an average daily temperature of 58° F., to an average of 73° F. within 2 days and to an average of 80° F. within 3 days. This sudden rise from a low average daily temperature to a high one increased larval mortality to 92.4%. It has been shown that rain and hot, dry periods do not greatly affect larval mortality. The importance of these two factors has been over-emphasized in the literature. Sudden heat waves have not before been suggested as causing increased larval mortality.

Borer activity and climatic factors have been studied by correlating them within 5-day periods. A climatograph for the microclimate of the plots within each 5-day period has been devised, plotting for the first time the average temperature with the average saturation deficiency.

The number of female moths in flight annually, the number of eggs laid per female per 100 plants per season and the total percentage survival have been studied and measured and related by the use of the population index to field populations over wide areas.

The population index is expressed by the formula $PI = (AB)C$, where A is the number of females in flight, B the number of eggs laid per female per 100 plants per season and C the total seasonal survival.

It has been shown that the magnitude of the population index shows the trend of borer population in wide areas, thus indicating that the physical factors causing variations in observational plots are also acting over wide areas. Temperature and humidity are generally similar in wide areas, while rain and wind are more local in character. It has previously been shown that wind and rain have little effect on larval survival, while temperatures of certain characteristics greatly increase larval mortality.

The biotic factors contributing most largely to annual fluctuations in borer populations during the period in the life cycle of the borer under study have been shown to be initial available moth populations, larval survival, egg production per female and egg mortality.

The years under study have been classified according to their favourableness to corn borer development. The year 1928 was favourable.

The years 1932, 1933 and 1936 were above average in favourableness, the years 1929, 1931 and 1935 below average in favourableness, and 1930 and 1934 were very unfavourable.

The biotic factors causing a decrease or increase in borer population in each year are as follows: during 1929, a decrease took place because of a low initial moth population and poor larval survival; in 1930, a decrease occurred because of extremely low larval survival; in 1931, an increase occurred because of very favourable larval survival; in 1932, an increase in borer population occurred because of favourable moth population and increased egg production per female; in 1933, an increase occurred because of favourable moth population; in 1934, a decrease occurred because of low moth population and low egg survival; in 1935, an increase occurred because of greater egg production per female and increased larval survival; and in 1936, an increase occurred because of a high moth population.

It has been shown that pupal mortality and corn refuse clean-up are two important factors influencing the available moth population. The climatic conditions causing pupal mortality in 1934 are given in some detail. Similar conditions were present only in the years 1927 and 1928 when large reductions in borer populations took place. These reductions are, no doubt, due partly to the clean-up of corn refuse and partly to pupal mortality.

The factors causing population fluctuations are complex, and in many cases, interdependent. The important factors, however, causing fluctuations in borer population have been found to be initial moth population, larval survival, egg production, egg mortality, pupal mortality and corn refuse clean-up. Temperature, especially temperature of certain definite characteristics, has been shown to have a great influence upon most of these factors, but especially upon the rate of larval establishment, pupal mortality, egg mortality, and the number of eggs produced.

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(Concluded)

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WORLD ECONOMISTS TO MEET IN CANADA

The fifth meeting of the International Conference of Agricultural Economists will be held at Macdonald College, Ste. Anne de Bellevue, Quebec, August 21–28, 1938. This Conference will be attended by Agricultural Economists from more than 25 countries.

The Conference was first organized in 1929. It came about as a result of discussions between Dr. C. S. Orwin, Director of the Agricultural Economics Research Institute, Oxford, England, Dr. C. E. Ladd, Department of Agricultural Economics, Cornell University, Ithaca, N.Y., the late Dr. G. F. Warren, Department of Agricultural Economics, Cornell University, Ithaca, N.Y., and Mr. L. K. Elmhirst, Dartington Hall, Totnes, Devon, England. The first meeting was held at Mr. Elmhirst's Estate; the second at Cornell University, Ithaca, N.Y.; the third at Bad Eilsen, Germany; and the fourth at St. Andrews University, St. Andrews, Scotland.

The purpose of the Conference is to bring together periodically Agricultural Economists from all parts of the world to discuss international economic problems affecting agriculture and to discuss common problems in carrying on research.

The officers at present are: President, L. K. Elmhirst; Vice-President, Dr. Max Sering, University of Berlin, Berlin, Germany; Honorary-Secretary, J. R. Currie, Research Department, Dartington Hall, Totnes, Devon, England. The late Dr. G. F. Warren was also a Vice-President. Each country may elect a member to the Council for every ten members but no country shall have more than three members. The Canadian representatives are Dr. J. F. Booth, Economics Division, Marketing Service, Dominion Department of Agriculture, Ottawa; Dr. W. Allen, Canadian Agricultural Commissioner, London, England, and Dr. J. E. Lattimer, Department of Farm Economics, Macdonald College, P.Q The arrangements of the Conference are in the hands of a committee of which Dr. Lattimer is Chairman and Joseph Coke, Economics Division, Marketing Service, Dominion Department of Agriculture, Ottawa, is Secretary.

Among those who will be in attendance are Secretary Wallace, United States Department of Agriculture, Washington, D.C.; Dr. C. Meyer, Berlin, Germany; Dr. V. Brdlik, Institute of Agricultural Accountancy and Economics, Praha, Czechoslovakia; Dr. S. L. Descartes, College of Agriculture and Mechanic Arts, University of Puerto Rico, Rio Piedras, P.R., West Indies; Mr. A. H. Cockayne, Director of Agriculture, Wellington, New Zealand; Prof. C. Lorenzoni, Florence, Italy; Prof. C. Ihrig, Budapest, Hungary; Dean C. E. Ladd, Department of Agricultural Economics, Cornell University, Ithaca, N.Y.; Prof. Asher Hobson, Department of Agricultural Economics, University of Wisconsin, Madison, Wis.; Prof. A. W. Ashby, Department of Agricultural Economics, University College of Wales, Aberystwyth; W. H. Senior, Department of Agriculture for Scotland, Edinburgh; A. W. Menzies Kitchen, School of Agriculture, Cambridge, England; Miss Ruth Cohen, Agricultural Economics Research Institute, Oxford; G. S. Bennett, Imperial Economic Committee, London, England; Prof. S. Schmidt, Krakow University, Krakow, Poland; Prof. P. Starcs, Jelgava, Latvia; Ramon Fernandez y. Fernandez, National University of Mexico, Mexico City; D. A. E. Harkness, Ministry of Agriculture, Government of Northern Ireland, Belfast; and Prof. H. C. M. Case, University of Illinois, Urbana.

The program will centre about four main themes:—Social Implications of Economic Progress in Present Day Agriculture, Land Tenure and the Social Control of Land Use, Farm Labour and Social Standards, and International Trading in Relation to Agricultural Development.

Round table discussions will be arranged on the use of International Statistics of Agriculture, Farm Management Research, Marketing Research, Price Analyses, Rural Rehabilitation and Resettlement. In addition, there will be a series of papers dealing with a wide variety of subjects.